Rehabilitation and Sports Medicine
Medicine Faculty from Göttingen University
(Prof. Dr. med. et Dr.rer.nat. Andree Niklas)

# Studies on the performance structure and relevant parameters determining individual performance in the Paralympic Sport Alpine Skiing
# – Case Study -

**INAUGURAL - DISSERTATION**

for the purpose of obtaining the doctoral degree (PhD.)

Sport Sciences Institute

Social Science Faculty

Georg-August University – Göttingen

in cooperation with

German Aerospace Center – Institute of Aerodynamics and Flow Technology - Göttingen

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Göttingen 2012

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## AKNOWLEDGMENTS

I would like thank the German Aerospace Center (*DLR*), German Academic Exchange Service (*DAAD*), Hamburg-Harburg University of Technology (*TUHH*), Sport Sciences Institute - Göttingen University, German Disabled Sports Association (*DBS*) and the Lutheran University of Brazil (*ULBRA*) for giving me conditions in different levels to do my doctorate here in Germany.

I would like to thank all the athletes who collaborated as volunteers of this research. My sincere thanks to Prof. Dr. Andree Niklas, Prof. Dr. Andreas Dillmann for supervising me and for making the accomplishment of this study possible. Also am I grateful to the Ph.D. Dr. Thais Russomano for the scientific guidance and by the incentives given in certain difficult moments of the development of this research.

My thanks are also extended to all the people of the German Aerospace Center (*DLR*) both in Göttingen and Harburg-Hamburg who contributed in the construction of this work as well as to all the people of the University of Göttingen especially from the Sport Institute.

I want to leave my cordial thanks to all those persons that were not reported at this time but that also contributed to the realization of this work. And finally, not least important, I would like to thank my family who believed that it would be possible to make the dream true.

Thank you very much!

Nelson A. C. Vinagre

# ABSTRACT

**Introduction**: The evaluation of athletes taking part in the sporting activities of the summer and winter Paralympic Games has advanced. However, there are few academic studies involving Paralympic Alpine Skiing athletes due to limiting factors, such as the need for appropriately simulating circumstances whereby the demand of the effort required during racing or in the sporting environment can be appraised. This study directed at athletes from the German Paralympic Alpine Ski Team (*DPS*), encompasses an overall evaluation focused on two main assessments, together with some complementary tests. It covers the period from the end of the Winter Paralympic Games of 2010 until the beginning of the international season of 2012. Most of the athletes involved are wheelchair bound and therefore race in the sitting classes (monoski), although two stand-skiers were also evaluated. Cardiopulmonary exercise testing took place using either a wheelchair (WC) on a treadmill or stationary bicycle, as appropriate, to check the parameters related to the physical conditioning of the athletes. A specific protocol was used for the evaluation of the wheelchair dependent athletes on the treadmill, whilst Holmann's protocol was used for the stand-skiers. The second form of assessment carried out as a part of the evaluation process was a wind tunnel (WT) investigation of air loads on the athletes**.** The load factors found in ergometric testing were indirectly compared with those obtained from the wind tunnel assessments. The study protocol was approved by the German Federal Committee on Competitive Sports and the Federal Institute of Sports Science. Subjects were recruited on a voluntary basis after provision of written informed consent. **Objectives:** The overall study aim is intended to bring forth new information regarding the performance structure of this particular sport, thus enabling the development of functional and physical activities (preventive and rehabilitative) so that improvements can be made to the performances in training, competition and daily life of athletes who have all experienced some form of spinal cord injury or upper limb amputation/deficit. It also aims to promote greater social inclusion with the transference of this knowledge to the lives of non-athletes with disabilities. **The specific objectives** for the athletes under investigation in the two main laboratories was to establish the use of equipments for the verification of measurable variables by checking the effects of load on the functioning of the cardiopulmonary system during spiroergometry, and the coordinative ability of the Paralympic athletes by assessment of their postural performance in the WT when subject to increasing wind speeds, checking also the relevance of the loading procedures on the Paralympic Alpine Ski athletes in both environments. **Methods**: The volunteers were submitted to a pre-test to detect cardiovascular diseases that could hinder their performance during spiroergometry and stress tests. The study was conducted on the basis of data collection from 5 wheelchair-dependent and 2 standing Paralympic Alpine Ski athletes; 5 male and 2 female. The first main experiment was conducted in the Exercise Physiology laboratory at the Sports Science Institute (*IFS*), University of Göttingen, Germany. Wheelchair ergometry was carried out by the WC dependent athletes using their own chairs on a treadmill, employing a pulley system and auxiliary force admission. The test was performed at a constant speed (2m/s). Load was increased every 3 minutes (20W) until voluntary fatigue. Blood samples were drawn from the ear lobe before and after testing to measure blood lactate concentrations. The assessment of the stand-skiers was carried out using a stationary bike. Load was increased every 3 minutes (40W for women; 50W for men) until voluntary fatigue. Blood samples were drawn from the ear lobe before testing, with each new stage reached and after testing to measure blood lactate concentrations. Cardiorespiratory responses were continuously measured using a portable electrocardiogram and gas analyzer in both procedures. The second main experiment was conducted in a subsonic, atmospheric, large low-speed wind tunnel at the Technical University of Hamburg-Harburg, Germany. Tests were carried out on the seated and standing skiers to investigate the relationship between posture and relative wind speed. A camera was positioned on the side of the WT section to capture stationary images of the skiers and these were used in the analysis of data collected during this experiment. The test consisted of 4 body positions held at 3 different wind speeds. Athletes held each position for 30s during which time 3 photographs were taken and the drag measurements collected. These images were used in conjunction with the aerodynamic values found. **Results**: The individual results presented during tests performed in the physiology laboratory and wind tunnel cannot be generalized, but must be seen in the context of an individual analysis by means of a discussion for each athlete. The general results of the anthropometric evaluations, the treatment of photographic records, and the questionnaires and field notes completed by the athletes and supervisor for both campaigns are compiled in tables, and are presented as a whole in the introduction to the

results. The athletes were able to carry out testing for both campaigns in accordance with the characteristics of the test (progressive loading) and the outlined protocol, with just one exception in the 1st campaign. From a biomechanical outlook, the sit-skiers were able to maintain regular arm propulsion as the test stages advanced, presenting a satisfactory level of "strides". The stand-skiers were able to maintain a near constant rate of cycles per minute. The load achieved by the athletes during the stages of the experimental session represents the Mechanical Performance ($P_N$), and the individual physiological response to the tests that were carried out is the Physiological Performance ($P_B$). The relationship between both variables is expressed as a percentage and is known as the efficiency. The measurement of $\dot{V}O_2$ and blood lactate levels were determining factors in the evaluation of the fitness condition of the skiers. Both tests were followed by lactate readings taken at two different intervals after test end to show the recovery of each athlete. Maximum heart rate was recorded during the tests in both campaigns. All measurements were taken immediately after each test ended and are shown in individual Tables for each athlete. By the aerodynamic experiment, drag force (**D**) and drag coefficient (**$C_D$**) values obtained from the subjects were plotted on 2 individual graphics, enabling a greater awareness of their performances. It is believed that variations in the ski clothing and the manner of wearing it can cause some negative interference with the results. Conversely, it is believed that the motor learning gained from the first experiment, the additional training that took place between the two campaigns, and anthropometric changes have brought positive results for the athletes. The results obtained from this assessment should have applicability for increasing understanding of those variables that can improve the postural performance of the athletes when training or competing. **Discussion:** The spiroergometry evaluation carried out to check the fitness of these athletes produced consistent and coherent results without exposing them to risk. The performances in 2010 and 2011 were similar in as much as the athletes were able to continue testing until the same stage, however, they performed this stage for a longer time during the 2nd campaign. Little difference was seen in the $HR_{max}$ between T1 and T4. It can be said that the physiological performance of the athletes continue to improve as their $\dot{V}O_2$ results were superior in the 2011 evaluation when compared to 2010. Despite the recorded level of lactate in some cases being higher at the end of testing in the second campaign, as compared to the first, the response of the volunteers can be considered to be better as recovery took place quicker and the lactate level readings were less subject to fluctuations. The aerodynamics evaluation was intended to take account of the amount of drag produced by the athletes and it generated innovative results without exposing the athletes to risk. In a comparison of the results for drag in 2011 with those of 2010, it can be seen that the athletes were able to reduce the drag produced by the posture offering most resistance. It can also be stated that there were deteriorations in the 2011 test performances of a few positions in relation to 2010, whilst in other positions the athletes always gave a better performance in 2011 than in 2010. A greater consistency in the results can be seen in 2011 when comparing the **$C_D$** values between the two years, as an increase in **$C_D$** for each position carried out was found with the increase in wind speed. Incorporating calculation of the **$C_D$** according to the frontal area of the individual in the 2nd campaign in 2011 brought with it even more accurate values. **Conclusions:** The skiers could perform the different load procedures in the spiroergometry assessment and in accordance with the recommendations of the International Council for Sport and Physical Education. The ergometric test conducted required athletes to learn how to manage their stamina, strength and coordinative capacities. The assessment of aerobic capacity may help with performances during training and competition, as the athletes must focus their attention on a range of demands that together, are largely met by the aerobic system. They performed better in 2011 than in the tests that took place in 2010, not only from a physiological point of view, but also from a coordinative perspective. The raw data could enable the athletes to have a better understanding of physiological responses. It would be of interest in the WT tests if the athletes could reproduce the exact same conditions for both campaigns by the use of the same equipment each time, the manner of using that equipment and also the postures held. The results obtained lead us to believe that there may be a direct relationship between the athlete posture, the use of the ski suit/equipment and the aerodynamic performance. The drag force generated by the body area, which is the drag area and volume as a function of air resistance on the Paralympic Alpine Ski athlete, may represent a significant difference to the outcome. The athletes must concentrate more on their posture and maintain a high performance of this when skiing; they should perform specific training aimed at strengthening the trunk, arms and neck in the case of sit-skiers, and the hip and leg muscles in the case of the stand-skiers.

# LIST OF ABBREVIATIONS

## CHAPTER I

**ADLs -** Activities of Daily Living
**AS -** Alpine Skiing (Alpine Ski)
**DLR (*Deutsches Zentrum für Luft- und Raumfahrt*) –** German Aerospace Centre
***DPS (Deutsches Paralympic Skiteam alpin)* –** German Paralympic Ski Team
**ET -** Ergometric Treadmill
***IFS (Institut für Sporwissenschaft)* –** Institute for Sports Sciences
**TUHH -** Technical University of Hamburg-Harburg
**WC -** Wheelchair
**WT -** Wind Tunnel

## CHAPTER II

**AD -** Autonomic Dysreflexia
**$A_D$ -** Drag area
**$C_D$ -** Drag Coefficient
**C1-7 -** Cervical Vertebrae
**CNS -** Central Nervous System
**CO -** Cardiac Output
**DFVLR (*Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt*)** – Former *DLR*
**D -** Drag Force
**DVT -** Deep Vein Thrombosis
**ET** – Ergometric Treadmill
**ECG** – Electrocardiography
**FEV1 -** Forced Expiratory Volume in 1 second
**$F_EO_2$ -** Percentages of inspired gases
**$F_ECO_2$ -** Percentages of expired gases
**HR -** Heart Rate
**$HR_{max}$ -** Maximum Heart Rate
**IPC -** The International Paralympic Committee
**L1-5 -** Lumbar Vertebrae
**MVV -** Maximum Voluntary Ventilation
**N-** Newton
**NS -** Nervous System
**PNS -** Peripheral Nervous System
**RQ -** Respiratory Quotient
**RR -** Respiratory Rate
**RER -** Respiratory Exchange Ratio
**S -** Area
**SCI -** Spinal Cord Injury
**SV -** Stroke Volume
**T1-11 -** Thoracic Vertebrae
**V-** Relative Velocity
**VA -** Pulmonary Ventilation
**VT** - Tidal Volume
**VC -** Vital Capacity
**$VCO_2$ -** Carbon Dioxide Delivery
**VE -** Expired Minute Volume
$\dot{V}O_2$ - Oxygen Consumption
$\dot{V}O_{2max}$ – Maximal Consumption of Oxygen
$\dot{V}O_{2peak}$ - Peak of Oxygen Uptake
**W**- Watt
**ρ -** Density

## CHAPTER III

**BDD -** Body Discomfort Diagram
**D Area -** Drag Area
**"e" -** equivalent $P_N/P_B$
**LA -** Lactate
**$P_N$ -** Mechanical output
**$P_B$ -** Gross output

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## CHAPTER III

### 2.1 Case number 1/ Volunteer (C1)

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## 2.3 Case number 3/ Volunteer (C3)



## 2.4 Case number 4/ Volunteer (C4)

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# I. INTRODUCTION

## I. INTRODUCTION

The sporting opportunities for people with disabilities have grown and transformed greatly over the last decades and the prospect of more changes to come over the coming years should further improve quality of life for the disabled. Increasing numbers of individuals with a disability, spanning all age groups, are currently becoming more involved with sporting activities. Increased accessibility and social inclusion for the disabled is occurring through the creation of initiatives all over the world, with the formation of targeted sports programs also playing a part in this action. Participation in sport has become more of an option for persons with a disability, improving quality of life and health.

The wheelchair has long been one of the fitness options for people who have suffered a spinal cord injury (SCI) resulting in paraplegia. The use of this equipment is fully integrated into the Paralympic Games. Many sporting activities directly related to wheelchair use are included with, for example, some athletics events as well as dance activities involving wheelchair use being incorporated into the list of sports organised by the International Paralympic Committee[1] (IPC). Additionally, wheelchair fencing features on the list of activities of the International Organization of Sport for the Disabled[2] (IOSD), whilst wheelchair basketball, curling, rugby and tennis are governed by International Federations[3] (IF Sports). Likewise, some Winter sports activities, such as Alpine and Nordic Skiing are open to wheelchair dependent individuals in competitions organised by the IPC.

Sport for athletes with a disability has existed for more than 100 years. In the 18$^{th}$ and 19$^{th}$ centuries, contributions were made which proved that sporting activities were very important for the rehabilitation and re-education of persons with a disability**.** Sport for people with a physical disability was introduced after World War II to assist the medical and psychological needs of a large number of people with injuries. New research aimed at methods for minimizing the consequences of their reduced mobility provided new ideas and possibilities for using sporting activity as a means of treatment and rehabilitation (The International Paralympic Committee).

### 1. Background

A Spinal Injuries Centre was opened in 1944 by Dr. Ludwig Guttmann at the Stoke Mandeville Hospital, Buckinghamshire, at the request of the British Government. It aimed to provide

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[1] **The International Paralympic Committee (IPC)** is the global governing body of the Paralympic Movement. The IPC organizes the Summer and Winter Paralympic Games, and serves as the International Federation for nine sports, for which it supervises and co-ordinates the World Championships and other competitions. The IPC is committed to enabling Paralympic athletes to achieve sporting excellence and to developing sport opportunities for all persons with a disability from the beginner to elite level. In addition, the IPC aims to promote the Paralympic values, which include courage, determination, inspiration and equality. The IPC was founded in Düsseldorf, Germany, on 22 September 1989, the IPC is an international non-profit organization formed and run by 165 National Paralympic Committees (NPCs) from five regions and four disability specific international sports federations (IOSDs). The IPC Headquarters and its management team are located in Bonn, Germany. The organization has a democratic constitution and structure, made up of elected representatives.

[2] An IOSD Sport is a sport for athletes with a disability on the Paralympic Programme governed by an **International Organization of Sport for the Disabled (IOSD)**. The IPC currently recognizes six IOSD sports on the Paralympic Programme.

[3] **IF Sports –** Eleven sports on the Paralympic Programme are governed by International Federations.

support and improve the health of those people who had sustained spinal injuries while serving in the armed forces. A new approach introduced the concept of sport as a vital part of the remedial treatment and total rehabilitation of disabled people. This rehabilitative sport evolved quickly into recreational sport, and within a matter of a few short years it progressed further to become a competitive sport. On 28th July 1948, the day of the Opening Ceremony of the Olympic Games in London, Dr. Guttmann organized the first competition for wheelchair athletes, which he named the Stoke Mandeville Games (Guttmann, 1976).

In the 1970's, professional researchers showed interest in the continued development of sport as a pursuit for and to include persons with a disability. Sports Science, the scientific discipline that studies human kinetics with the aim of improving sports performances, incorporating research in areas such as physiology, psychology, biomechanics, performance analysis, nutrition and sports technology (Shepard, 1994), began to be applied also to sport for people with a disability.

Alpine Skiing (AS) was one of the pioneering sports featured in the first Winter Paralympic games held in Sweden in 1976 but it was not until Austria in 1988 that the category of sit-skiing was included as a paralympic sport. Following on from the introduction and consolidation of Alpine Skiing as a paralympic sport over these two decades, it has developed further to become an interesting alternative activity that can be performed in a social context as a leisure and fitness pursuit for people with disabilities. This means that from the very top of the performance sport and sports science, through to education, fitness and leisure, it is possible to take vanguard information and adapt and apply it to the ordinary non-athlete citizen who might require health care and assistance. In the search for new alternatives aimed at reducing the damaging effects of immobility and improving sports performance in general, it is possible to promote the idea of sport as a means of assessment, rehabilitation and social inclusion.

## 2. State of the Art

The Paralympic games that were first conceived in the United Kingdom returned to London in August 2012. It can be said that many transformations within society have taken place in the lives of people with special needs in the 64 years since the advent of the Paralympic Games. Technological innovations in the means of communication in the last decade has contributed to a changes in how society perceives people with disability, in such a way that the media increasingly seeks to link adapted sports to being examples of success.

This premise might perhaps be questioned as culturally, socially and technologically, adaptive sports develop at a much slower pace than those for non-disabled people, as the need to create short-term solutions for people suffering a crisis must take priority. Despite the complexity of the process though, it is worth mentioning that many projects developed in the last 4 decades have occurred primarily with the intent of improving sport for people with special needs.

The last years of the 1980's and continuing into the 1990's saw the creation across all continents of centres for research into sport for people with disability. Studies in the area of exercise physiology began to take place in the major sporting activities with the aim of ascertaining the capacity for adaptation of people with physical and/or mental impairment. In Germany at the end of the 1990's, projects were developed using swimming pools to conduct a complex distributed performance diagnosis for disabled people in competitive sports, in comparison with the able-bodied (Niklas, Ackermann, Ungerechts, Hottowitz, Fuhrmann, 1998). At the beginning of 2000, projects related to athlete performance and diagnostics for extreme Winter sports raised the evaluation process for Paralympic athletes to the same standard as for Olympic athletes, starting a new phase in the perception of handicapped sports.

This present study seeks to continue this process of evaluating people with disability in the same manner as the non-handicapped by submitting athletes from the German Paralympic Alpine Ski team to both a routine test and to a less typical evaluation process, in order to observe overall responses. This could ultimately benefit not only the ski team themselves but also non-athletes with disability. The focus was on the concept of performance structure for Alpine Skiing, noting characteristics of the physiological response to exercise, appropriately adapting methods of fitness assessment and noting aerodynamic responses. Biomechanical concerns relating to posture, motor learning and motor development for the disabled were also considered, taking into account those people with disability who wish to partake in sport as a means of avoiding greater health risk implications or that wish to practice sport as a rehabilitative process for improving motor skills.

## 3. Motivation

The motivation behind this study was in part driven by the possibility of carrying out research that would allow the use and unification of different areas of expertise (Figure 1). A physiology investigation of handicapped sportsmen together with a wind tunnel (WT) investigation of air loads on humans could bring advances related to the quality of life and health of people with disabilities. Additionally, a further important motivation factor was the idea of promoting social inclusion of the disabled by applying study findings to non-elite scenarios through the organization of the scientific information.

| Exercise Physiology | Biomechanics | Aerodynamics | Social Inclusion |
|---|---|---|---|

Diagnostics achievement for specific sport

Paralympics Alpine Skiing

Wheelchair-dependent

Figure 1: Research areas related to the study

## 4. The Research

### 4.1 Topic

A description and analysis of results from an interdisciplinary evaluation performed with German Paralympic Alpine Ski athletes. This included how it links to the development of structured physical activities from a preventive and rehabilitative perspective with a view to improving activities of daily living (ADLs) for wheelchair-dependent victims of spinal cord injury and for those with upper limb deficit or amputation.

## 4.2 Problem Definition

A lack of access to the evolution of an interdisciplinary evaluation process focused on improving cardiorespiratory performance and posture in people with impaired mobility in the lower limbs or an absence of some limbs. When combined with the physical limitations and physiological effects generated by disability, this can result in people remaining without the complete information regarding their health condition. Additionally, a lack of knowledge may continue related to the potential for prevention of deterioration of the disease pathological process, ignorance of the rehabilitative benefits that can result from sport participation, as well as a lack of understanding of specific preparation requirements for individual sports.

## 4.3 Description of the Research

After consideration of the context of the study, the participants involved and the question it is intended to answer, it was decided to opt for a cross-sectional investigation of the work routine from the perspective of before/after the ski competition season within a paradigm of quantitative/qualitative research, although it is a case study given that the data will be quantified, described and analysed individually.

**a. Subject Selection -** The selection of participants as subjects for this study resulted from contact between the Dean and Executive Committee Speaker of the School of Medicine (University of Göttingen) with the *Deutscher Olympischer Sport Bund*[4]*(DOSB)*, Sports Medicine Research Centre as part of its mechanism as a sports-medicine investigation centre licensed by the *DOSB*.

**b. Ethics -** The study protocol was approved by the *BL des Deutschen Sportbundes und des BISp*[5]. Subjects were recruited on a voluntary basis after provision of written informed consent.

**c. Tests -** The volunteers were submitted to a clinical evaluation before the main experiment campaign. A pre-test was also conducted to detect any cardiovascular disease that could hinder performance during the spiroergometry and wind tunnel tests. The role of this research was the accomplishment of successive test campaigns involving the Paralympic Alpine Ski team athletes in the laboratory and wind tunnel.

## 4.4 **Objectives**

### General Objective

The overall approach of this study intends to bring innovative information to the performance structure of this form of sport, thus not only enabling the development of functional and physical activities (preventive and rehabilitative) so that improvements can be made to functional performance in training, competition and daily life of the athletes, all victims of spinal cord injury or having upper

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[4] DOSB - German Olympic Sports Federation.

[5] BL - BAL was once called "Federal Committee on Competitive Sports". This is a kind of "Council of the Gods" for competitive sports of Germany, now part of the DOSB. BISp. - Federal Institute of Sports Science, based in Bonn.

limb amputation/deficit. It also aims to enable greater social inclusion with the transference of this knowledge to non-athlete people with disabilities.

**Specific Objectives**

The study objectives for the German Paralympic Alpine Skiing athletes were:

*in the Exercise Physiology Laboratory*

- To establish the use of spiroergometry procedures for the verification of general fitness, the function of the cardiopulmonary system and to define the conditions of training and load control for each athlete.
- To check the values of sub-maximal and peak oxygen consumption.
- To check the relevance of the loading procedures on the Paralympic Alpine Skiing athlete.

*in the Wind Tunnel*

- To check the effects of air load on the coordinative ability and relevance in the assessment of the performance of the Paralympic athlete's posture.
- To check the values of the aerodynamic forces offered by the body of these athletes in four different positions during their performance.
- To check the relevance of the procedures for loading on the Paralympic Alpine Skiing athlete.

### 4.5 Hypotheses

The research hypotheses for this study will investigate whether:

• The laboratory spiroergometry evaluation contributes to a better assessment of athlete performance of Paralympic Alpine Skiing;

• The Wind Tunnel Test contributes to a better assessment of the Paralympic AlpineSkiing athlete;

• It is possible to compare the specific evaluation of the load (drag force) generated by a Paralympic skier in the wind tunnel with the load generated in exercise tests;

• It is possible to develop a performance structure (preventive and rehabilitative) through this evaluation process of the Alpine Skiing team that can improve functional performance in training, competition and daily life of the athletes, all victims of spinal cord injury or having upper limb amputation/deficit.

### 4.6 Rationale

The study of the performance structure of Alpine Skiing and of the preparation procedures for training and competition may bring new concepts in the structuring of skills to form part of the training for this type of activity, so no harm is caused to the postural or circulatory health of participants.

### 4.7 Sample

This study was based on the collection of data from 5 wheelchair-dependent and 2 standing (5 male and 2 female) Alpine Ski athletes for experiment 1, and subsequently, 4 wheelchair-dependent and 1 standing (3 male and 2 female) Alpine Ski athlete for experiment 2. These well-regarded athletes form the subject matter of this study with each athlete being individually analysed, one by one. This small and heterogeneous sample lends itself to the use of case studies for the methodological trend.

## 5. Set of themes and implication in the development of the study

## 6. Methodology

### 6.1 Adopted Paradigm

The subjectivity and extent of this theme is so evident that even with the application of bio-physiological sciences and physics, there is no definitive rational explanation for the strong performances shown by some athletes in their respective sports. This has encouraged the development of new evaluation techniques and work proposals for application to the physical, motor, psychological and social capabilities of physically disabled people (Vital *et al.*, 2002).

Defining the methodology of a research protocol is one of the numerous decisions and directions that the researcher must consider when conducting an investigation (Turato, 2003). The planning of such serves as the pathway that the researcher will follow in the search for answers to the original question posed, and it helps the understanding not only of the product of the scientific investigation but of the process itself. It is the methodology that defines the performance of the study.

Taking into consideration the context, participants and question this study is intended to answer, it was decided to evaluate the data of a specific point in time from the 2 year study period, inside the perspective of a qualitative study. The choice of methodology was linked closely to the problem it was intended to answer, as the collated data would not only be quantified but also interpreted (Turato, 2003). The study did not intend to establish generalizations but rather to contextualize the information considered to be relevant.

This study focuses on the test results, reported observations and data interpretation collected from two blocks of experiments conducted over an eight month period of time. The participants of the experiment were drawn from the athletes of the *Deutsches Paralympic Skiteam alpin*[6] (*DPS*) who each presented an account of their life story to date. Although the researcher has no previous history or experience of involvement with this particular form of sport, account should be taken of his experience with other varieties of sporting activity and techniques. This knowledge when applied to the present activity considered by this study, qualifies him to assess the athletes in a manner that initially contributes to the advancement of knowledge related to the sport in question, and can subsequently add to the evolution of adapted motor activity.

The four evaluative sessions comprising of treadmill spiroergometry, stress tests using an ergometric bicycle and aerodynamics testing performed in a wind tunnel, were carried out in two different settings. The first and fourth sessions took place in the exercise physiology laboratories at the *Institut für Sporwissenschaft* [7] (*IFS*), University of Göttingen, whilst the second and third sessions were conducted using the wind tunnel facilities at the Technical University of Hamburg-Harburg (TUHH) located in the same city in northern Germany.

Two evaluative campaigns were achieved with each consisting of two sessions carried out over a two day period, thus making a total of four sessions completed. The first campaign consisting of physiological and evaluation assessments, took place on the 1st and 2nd November 2010. Activities

[6] **Deutsches Paralympic Skiteam alpin –** German Paralympic Ski Team.
[7] **Institut für Sporwissenschaft –** Institute for Sports Sciences.

on the first day included the taking of medical histories for each participant as well as clinical, cardiopulmonary, and stress tests. Evaluation tests on the second day involved submitting the *DPS* athletes to a wind tunnel aerodynamics test, requiring them to adapt to a new environment. Each athlete was asked to perform the different body postures that would be used in a racing event in order to generate data for the aerodynamic forces encountered, whilst also taking into account variations in the wind speed. The second campaign took place on the 12th and 13th August 2011, with the order of evaluations being reversed due to restrictions in equipment availability and time of the athletes involved. A report was completed immediately after each session finished for both campaigns to ensure that all records were organised in the shortest possible time in order to avoid data loss and undue post-campaign influence from judgement values.

Various resources for data collection were used including anthropometric measurements and clinical, photographic, physical, and physiological records. The researcher also included selective observations and questionnaires for the analysis. Through systematic observation over the two periods of assessment, the researcher sought to monitor and record the performance of study participants in order to understand the significance of the evaluation process on the physiological, physical and postural deportment of each individual athlete (Vital *et al.*, 2002). Furthermore, through objective questions directed at both the athletes and technical team members, the researcher sought to collect detail regarding the personal impressions held by each one in respect to the series of test being applied. Additionally and where possible, elements of the study that could be reproduced in the same form over the two campaigns were conducted in order to establish comparisons between the results for each session.

### 6.2. Consideration Regarding the Investigation Methodology Adopted

A descriptive research belonging to the interpretative qualitative approach was chosen as it is believed that this method lends itself better to this research, that is, a case study of a specific sports team and its participants. The concepts embodied by ethnography were also considered in the relentless pursuit of the methodology that would be best suited to this work. This essentially consists of the description of a system of cultural meanings of a particular group, with special attention paid to the behaviour of the subject as a group member, and at times it appeared to be the best option for the study. However, it was thought best not to base the research on this methodological approach given the constraints of there being insufficient time to conduct a longitudinal study. Ethology[8] was also contemplated as a methodological approach for this study combining aspects of functional assessment (exercise physiology, biomechanics) with the adapted activity of the physically disabled.

The evaluation periods took place over a short time period, allowing us to say that the sessions were closely linked and complemented each other. Tools such as photographic records, video footage and observations were crucial for the analyses performed along the length of the study. A

[8] **Ethology –** The study of animal behavior and their adaptation to environmental conditions.

questionnaire was introduced as a means of complementing the evaluation process, being applied to sessions 3 and 4 only, to enable collection of additional information not obtained in the first interviews and also to allow the value judgements of the athletes themselves to be introduced into the research.

Photographic records were divided into two categories and played an important role for data analysis, especially for those experiments carried out in the wind tunnel. The first category did not follow a rigid itinerary and included photos taken over the four sessions. Their content was considered to be broader with the intention of collecting more detail. This brought records that would serve as a documentary contribution, allowing a comprehensive analysis of the study and with this, enabling triangulation between all the information collected. The second photographic category related specifically to the experiments conducted in the wind tunnel. These captured evidence of the posture presented by athletes for each phase of the aerodynamics evaluation, including the measure of force applied to them for each of the race positions performed. This second category of photographic data facilitated the creation of a dynamic analysis of the postural performance of each athlete, similar to that of film footage, trying to document the real life conditions experienced in a race.

Video equipment was used during two different sessions only and followed a different agenda for each. A portable camcorder was used during the first campaign to record the biomechanical performance of each athlete undergoing a cardiopulmonary test on a treadmill. For the second campaign the function of recording as much information as possible in the evaluative context of the wind tunnel was carried out by a professional team of journalists, with a copy of the recorded material subsequently being provided to the researcher.

Observation, a strategy that also typifies a descriptive study, was used as a complementary tool to add to the range of information collected. The researcher acted as a passive observer in the first session and subsequently as an active observer for the remaining ones. Information was gathered and records made after completion of each session with the aim of adding context to the findings relating to the participants, a group of people having both very specific and yet also heterogeneous characteristics, something that did not cease to be a limitation of the study.

It is believed that by proceeding in this manner, the recommendations have been met regarding investigative procedures that should be adopted when using a descriptive research, with this methodology being comprised of the description of a given group, requiring distinct methods and means of collecting information. Considering the specific nature of the research proposed and taking into account both the advantages and limitations that the choice of one method can have over another, it is believed that the methodological approach adopted by this study was the most appropriate. The stages of the study will now be outlined with the intention of presenting the strategies used in the research process.

### 6.3 Research Stages

The investigation process was structured around distinct phases with the first relating to ***defining the area of study***. At this time consent for the study was sought from those responsible for the Paralympic Alpine Ski team and from the athletes involved directly in the investigation. The signed consent forms completed by the athletes can be found in Appendix 1 along with documents from the Paralympic Sports Confederation requesting that the evaluation of the athletes be conducted. Table 1 presents a summary of the form adopted for this investigation.

**Table 1. Phases and Steps of the Investigation Process**

| PHASE | STEP | ACTIVITY |
|---|---|---|
| 1 | **Defining the area of study** | Choice of subject matter<br>Defining problems<br>Defining objectives<br>Defining the research questions<br>Hypothesis |
| 2 | **Defining the techniques for collecting information** | Data collection tools |
| 3 | **Defining the subjects** | Defining the experiment participants |
| 4 | **Data collection** | Data collection through use of the selected tools<br>The researcher task as facilitator and observer |
| 5 | **Literature review and reflection** | The study itself |
| 6 | **Description and analyses of data** | Description and analyses<br>Discussion and interpretation of data |

The order of presentation should not be seen as a linear path as the investigation process itself is complex, with different combinations that make up a part of the whole. For example, the development of the literature review is defined in the fifth phase, however, the process of seeking out relevant publications that addressed the issues in question and that contributed to a better understanding of the phenomenon intended for study were carried out continuously over the course of all the phases, without interfering with the investigative process. As previously mentioned, the first phase sought to define the area of study, thus involving the choice of theme, defining the objectives and potential problems, outlining the research questions, forming the hypothesis, and entailing an initial period of negotiation with the participants.

The choice of theme arose due to an interest in performing an evaluation of the *DPS* team in two different situations in two different environments, primarily to know if the recordings made in both tests could be compared. The subject matter was also motivated by an opportunity to develop innovative strategies for evaluative intervention, arousing the interest of both trainers and athletes alike with the possibility of conducting an experiment rarely before done. It should be noted that the cooperation between the *Deutsches Zentrum für Luft- und Raumfahrt*[9] (*DLR*) and the Institute of Sports Science was essential for this research to be completed.

[9] **Deutsches Zentrum für Luft- und Raumfahrt –** German Aerospace Centre.

The defining of the problems resulted from a long period of discussion to ascertain the characteristics of the research subject and the methodological approach that would be followed. Several versions were considered before arriving at the final definitive form of the investigation. Negrine (1999) suggested that the theoretical basis of a qualitative research, the formulation of objectives, and the defining of the research questions for an investigation is only possible after identifying the problems. These strategies served to give direction to the investigation process.

For the second phase of the research covering ***defining the techniques for collecting information***, it was thought to perform 4 evaluative sessions to be conducted two at a time, over two different calendar periods. Each evaluation block would permit the athletes to be assessed in two different laboratories. The first block was aimed at performing cardiopulmonary testing and the second for conducting aerodynamic testing. Alongside the accomplishment of these two principal test experiments together with the specific data collection relevant to both, other techniques for gathering information were also used in order to enrich the records. Among these techniques were the recording of clinical records, anthropometric measurements, interviews (medical history), observations, questionnaires, photographic records and video footage. A literature review of information collection techniques for a qualitative research helped define the tools used for this investigation (Molina, 1995/ 1999). A greater possibility exists for being able to triangulate data in a qualitative study when the collection of information is extensive and from many sources. This collection of records as a whole served to support the description, analysis and interpretation of what was proposed by this study.

In the third phase, ***defining the subjects*** who would take part in the investigation process, the entire *DPS* team were invited to participate. It was left to the individual athletes concerned to decide if they wished to be included in the experiment and information collection process of the study. Although it was initially thought that some athletes might not be able to play a part, this did not in fact prove to be the case. Evaluation practices had previously taken place over the last ten years at the *IFS* facilities and there was a concern that the mobilization and organization of the *DPS* team and the planned experiments be conducted to a standard form. The initial goal and objective of the *IFS* was to conduct a quality evaluation by bringing together the entire *DPS* team to be evaluated, giving recognition to the value of the suggested proposal and an appreciation for the technical and scientific competence of the institute known for their performance. The University of Göttingen supported the intention of the researcher, financing a part of the study related to the exercise laboratory.

The initial idea of being able to conduct the study with the *DPS* athletes was very important, because it set the specific group that would be the subject of the research, even though this group was very heterogeneous in its composition. The fact that the location for the evaluation already existed and that the leadership at the *DPS* already had the desire to evaluate the members of the Alpine Ski team, facilitated greatly the rapid formation of the study group without causing problems for the participants. The group adopted as the focus for this study numbered seven in total, with ages ranging from 17 to 40 years. To identify the participants, each was labelled initially with the letter “S” for subject together with a number allocated to each member, using 1 to 7, representing the order in which they would complete the tests for each session.

We were aware that it would be no easy task to bring together this voluntary group of participants, principally because the entire team was based in southern Germany whilst the experiments would be conducted in the centre and extreme north of the country. In addition to difficulties caused by the costs that would be incurred by the relocations, there was also some doubt about the degree of support the experiments would have from the athletes themselves. Despite all this, the German Aerospace Centre together with the University of Göttingen funded the study. At the same time, the professional and academic relations between the team doctor and the coordinator of the Department of Sports Medicine at the University of Göttingen enabled the almost immediate integration of the whole team that would participate in the experiment. By setting out clearly the characteristics of the group, we sought to reinforce the links with the volunteers, with whom we began to provide feed-back on information and strategies that were being determined and the cutting-edge information that would be collected from the experiments.

The ***data collection itself took place*** in the fourth phase, with the research team being involved in the direction of the experiments and collection of the data through use of the previously selected tools. The structure of the experiment sessions conducted in this study was broken into two distinct periods. The sessions took places during mornings and afternoons from 9h until 18h, and were separated into two blocks of evaluation of the *DPS* athletes. The first campaign comprised of 7 athletes, whilst the second had only 5 athletes, with 2 having ended their careers in the interim period. In this phase of the study it was also possible for the researcher to direct the experiments as an organiser, and also as an observer of the sessions.

From this point on the report centres on the instruments used for data collection, with consideration given to gathering information from a variety of sources in order to enlarge the understanding of the study. After fully contemplating and understanding both advantages and disadvantages of using observation as a data collection tool, it was decided to use the forms of passive and active observer. The researcher acted as a passive observer for the first session only, with the role of recording as much information as possible during the experiment. It also served to help integrate him gradually into the context of the evaluative team and with the athletes themselves. The role of the researcher as an active observer, however, was to make observations even though directing the session and interacting with the athletes. The observations made enabled a more accurate picture of the comportment of the athletes during the sessions and also formed a significant exercise for the recording of information. The records for observations made whilst both monitoring and directing the sessions, were made on the spot either during or immediately after each session. Whilst acting as either a passive or active observer for the assessments, the researcher recorded everything considered to be relevant and that could be used in the drafting of the final report based on the data collected in this phase.

Table 2 summarizes the data collected in the different phases of the study in order to give a sense of the scale of information gathered.

**Table 2: Summary of Information Collection**

| **Stage of study** | Nº Sessions | Nº Clinical Records | Nº Tests | Nº Field Notes | Nº Questionnaires | Nº. Photographs taken | Nº Total Observations | Vídeo tapes (minutes) | Vídeo tapes (minutes) used directly in the Study |
|---|---|---|---|---|---|---|---|---|---|
| Experiment I | 1 | 7 | 6 | 6 | -- | 235 | 6 | 50’ | 50’ |
| Experiment II | 1 | -- | 7 | 7 | -- | 307 | 7 | -- | -- |
| Experiment III | 1 | -- | 5 | 5 | 10 | 233 | 5 | 120’ | 12’ |
| Experiment IV | 1 | 5 | 5 | 5 | 10 | 309 | 5 | -- | -- |
| Total | 4 | 12 | 11 | 23 | 20 | 1084 | 23 | 170’ | 62’ |

Once being in possession of all the collected material, a ***literature review*** was conducted so that a subsequent comparison of data could be made in the next phase, such as for example, the analysis categories with the up-to-date theoretical background. A lengthy literature review was performed allowing a period of reflection to take place regarding the study theme. As an example, it can be mention some authors that were consulted in the areas of exercise physiology (Niklas, 1987; Vanlandewwijck, 2001), aerodynamics (Bendig, 1975; Watanabe, 1977), motor adapted activities (Van der Woude, 2006) and motor learning and development (Schmidt, 2001; Gabbard, 2000).

The sixth and final study phase involved ***description and analysis of the data,*** at which time the final report was written, with conditions being right for making the final evaluation of the research, drawing some conclusions, and detailing and outlining future prospects.

## 6.4 Data Collection Tools

### 6.4.1 Clinical Records

The athletes were submitted to a pre-test (laboratory tests and echocardiography) to detect the potential risk of cardiovascular diseases that could impair their performance during the research. This was carried out together with the Rainer Jung Rehabilitation Centre, working in cooperation with the *IFS*. A copy of the protocol used for conducting the clinical examinations of the athletes can be found in Appendix B.

### 6.4.2 Physiological Records

The *IFS* provides excellent facilities and in particular, a laboratory equipped with a high-performance ergometric treadmill (ET) with a pulley system for cardiopulmonary exercise testing and analysis, suitable for the purpose of assessing oxygen consumption for wheelchair (WC) dependent users. The principal piece of equipment provided in the laboratory is the SATURN 300-125R treadmill (*hp cosmos sports & medical gmbh, Nussdorf-Traunstein,* Germany). This device is located in a central position of the room and is set at ground level, therefore having the advantage of being very accessible for the tests conducted with WC athletes. The treadmill is mounted in such a way that the operating systems (mechanical and hydraulic) are located below floor level. The operating speed range for the treadmill is from 0-40km/h (0-11.1m/s), although the stress test performed for this research was made at a constant speed of 2m/s.

The pulley system is a device external to the ET that must be connected to the WC via a rope, making it possible to measure the force from 10W to 300W (Niklas, 1987; Vanlandewijck, 2001). A rail is fixed to the wall behind the WC and the pulleys are mounted on this rail in two different axes. The rope that is attached to the WC is guided by two pulleys. The load at the rope end can be increased (i.e. 20W each 3 minutes) during the course of the exercise.

Two computers were used during the experiments with both using specific software for their purpose: a desktop computer with an interface for control of the treadmill; a laptop computer for monitoring the spiroergometry. Additional equipment used included a spiroergometer, model Metamax 3B (*Cortex Biophysik GmbH, Leipzig,* Germany), portable electrocardiograph 3-channel EKG AT-4 (*Schiller AG*, Switzerland) and a lactate analyser SCOUT (*SensLab GmbH, Leipzig,* Germany). The sit-ski athletes performed the test, appropriately dressed, and using their own personal WCs, whereas the stand skiers used an ergometric bicycle. In both cases the athletes used a heart rate frequency meter, *Polar® HR Set* (*Polar Electro Oy HQ, Kempele,* Finland).

The laboratory has a computerised system of control for the treadmill and there is also a data processing program to maximise the use of the equipment. The spiroergometer used in the experiment is robust and mobile. The method Breath-by-Breath was used and some principal characteristics of the equipment can be found as a Table in the Annex 5 (Metamax).

### 6.4.3 Aerodynamic Test Records

The TUHH has a wind tunnel (WT) of large dimensions and low velocity, providing excellent facilities for the analysis of human aerodynamic performance in sport. The main equipment provided by the laboratory is the wind tunnel which is operated in a closed circuit, called the "*Göttingen*" mode. The dimensions of the test section are 5m in length, 2m in height and 3m width, and it is positioned approximately 2m above the floor level of the laboratory. The operational speed range for the wind tunnel is from 0-40 m/s (0-144 km/h), although the test was conducted at a maximum velocity of 30m/s (108 km/h).

Positioned below the floor of the WT testing section is a scale, an instrument for measuring the force applied to the athletes during testing. It is an external device to the WT, which provided the facility of being able to attach skis to it, enabling the force to be measured along three different axes.

The skis were secured to a wooden plate, which supported the equipment whilst at the same time preventing their movement during testing. This wooden plate was in turn attached to the balance that provided the measure of force applied to the athletes. The athletes conducted the test using their own skis (mono or double) and dressed appropriately for the situation.

The laboratory has a computerized control system, together with a data processing program to maximise the use of the equipment. Three computers were used during the experiment: 2 desktop computers with an interface for controlling the WT and recording the force applied to the athletes; 1 laptop on which to record and sort the photographs.

#### 6.4.4 Medical History

In qualitative research, the interview represents one of the basic instruments for the collection of information, together with observation (Molina Neto, 1995/1999). In this study a medical history was taken which lasted about twenty minutes for each athlete and took place in a separate hall from the physiological laboratory. The types of question addressed were focused and closed questions. The list of questions used for the medical history can be found in Appendix D.

The structure of the medical history questions for this study were organised in a manner that would gain the most information about each participant and their life story. The information collected included what was diagnosed from a clinical, physical, motor and behavioural point of view, as well as their personal experiences of their disability and the sport of alpine skiing in which they had chosen to compete.

All records were presented to each study participant after completion of their case history so they could read their responses. This strategy was used to try and guarantee that the recorded answers corresponded exactly to the information provided at the time of the interview. It was emphasised to the respondents when adopting this procedure that they could modify their statement if they deemed it at all necessary. Final analysis of case histories was made by the researcher, enabling him to formulate personal comments relevant to each athlete.

When organising the theoretical core of the study, it was realised from the literature search relevant to the evaluative process of Paralympic Alpine Skiing that more studies were found related to biomechanical aspects of skiing and physiological aspects related to other forms of sport. Aerodynamic tests with skiers had also already been done although with Olympic athletes (Bendig, 1975; Watanabe, 1977). However, very little was found in the review related to the evaluation process and training of Paralympic Alpine Skiers. Although there are a few publications about cardiopulmonary performance for the Paralympic Alpine Skiing sport, we sought to conduct the tests using wheelchairs and an ergometric bicycle with the athletes of the *DPS* in order to organise hard data for the athletes evaluated in the laboratory.

Therefore, in this investigation, we stayed with the clinical, physiological, physical, postural and personal perceptual records collected through the questionnaires, to establish interpretations of the developmental continuum for each of the *DPS* athletes. The sum of these factors was what gave support to our findings and to the limitations also suggested by a study of this nature.

### 6.4.5 Photographic and Video Records

Photographic records were used as a strategy for documenting the development of the study participants in different contexts over the course of the evaluative sessions. Our concern was to organise them into individual photographic albums registering the session to which they related. This feature was used primarily as a plan for gathering information associated to the postures presented in the wind tunnel tests. However, it was also used to document spontaneous situations as the camera was inserted into the routines of the sessions as another means of interacting with the environment in which the athletes were being evaluated. As many pictures as were deemed necessary were taken so that these could form a good photographic collection for the study. Insufficient resources to cover all sessions of the study meant that video recordings were made for only the sit skiers' assessments during the first evaluative session. The equipment was positioned to the side of the treadmill and the filming was focused on the motor performance and posture aspects of those evaluated. Although we were unable to make a record of all the athletes involved, the footage that was taken was of great value in supporting the description and analysis of the data collected during the investigation process. Also, it allowed us to conduct the exercise of observation and description of what we saw or were able to observe, being used more as a resource for allowing a subsequent review of the scenes that escaped our perception at the time of the evaluation process itself.

In the fourth session, video footage was recorded by a professional team of journalists from the German Aerospace Centre with the undertaking of recording images of the progress of the work. This presented the opportunity to have access to a recording of an evaluation session made from the pre-determined agenda of a film taken for journalistic purposes, giving material edited from another perspective of a broader scenario rather than the usual assessment of the athletes, constituting an unusual and interesting addition to the study.

### 6.4.6 Observations and Strategies for Recording Observations

The observations became an important tool for the collection of data in this study. According to Negrine (1998), effective observation should have some basic principles, such as:

- The more descriptive it is, the better the information analysis will be;
- The records must not contain value judgements;
- The depth of observations can provide sufficient information to conduct analysis and interpretation of the data.

For this study and bearing in mind the above recommendations, the process of observation was carried out in the following way: The researcher assumed the role of a passive observer for the first session only during the process of research information collection, subsequently changing in role to that of active observer for the remaining sessions.

When acting as passive observer, the researcher did not participate in the events but only observed and recorded things as they occurred. His participation was passive, that is, he did not direct or personally take part in the session, though he could at times interact with the group. The observation strategy for the different experimental sessions was to selectively observe, where the observer closely monitored the subject being evaluated in the session and described the whole trajectory of the observed participant at that moment.

Negrine (1999) states that from observation guidelines created through some basic questions, situations emerge that can be observed and that are closely related to the research being conducted. At the same time, it should be reduced or enlarged according to the wishes of the researcher, making the selective observation with pre-established aims. Records of the observations of the conducted sessions were made in a descriptive report before, during and after the end of each evaluation.

As an active observer, together with the entire technical team, the researcher assumed the role of facilitator and observer. As soon as observations of the focus group were completed, it was wanted to compare the data collected with that from the literature, which proved not to be an easy task due to difficulty in finding literature in this area. Only after making comparisons with this data could a critique of these evaluation practices be commenced.

#### 6.4.7 Questionnaire

The questionnaires were structured and the questions were objective, closed and focused in a multiple choice form. There were a few open questions in order to facilitate the ease of participant response. A copy of the question list used and the answers from the can be found in introduction of the results. The questionnaires were submitted in advance to the athletes, trainers and medical team by electronic means, so they could familiarise themselves with the format. Subsequently, the questionnaires were completed immediately before and after the evaluation sessions 3 and 4 at the locale where the tests were being conducted. All study participants that were in the 2$^{nd}$ campaign took part and responded to the questionnaires, demonstrating their degree of involvement in the process and the trust they held in the researcher.

The structure of the questions was organised in order to obtain the most information relevant to the personal perceptions of the participants from the evaluations completed regarding training, the physiological and aerodynamic evaluations, the sport in which they compete, their expectations of alpine skiing and training, competitions and quality of life.

The units of meaning and analysis categories, which were also presented to the athletes indirectly through the questionnaire and throughout the entire study, enabled analysis of the collected data. After conducting the final analysis of the applied questionnaires, the researcher was able to formulate personal comments for each of the athletes involved, taking into consideration the perception of the athlete, the trainer, and also the researcher himself.

#### 6.4.8 Analysis of Competition Video and Documentaries

The video recordings directly related to alpine ski competitions helped greatly in the observation and analysis of the postural performance of the athletes involved, allowing the researcher to better reflect on the direction to be taken for this investigative process. The recordings used refer to the IPC Alpine Skiing World Championships of 2011 that took place in Italy (Sestriere).

Some documentaries were found relating specifically to the area of training for Paralympic athletes. Given the substantial content presented by these and as such the importance of some of the statements provided during the course of the documentaries, this motivated in some cases the making of a transcript of the theoretical content of the program. These documentaries were produced mostly by the British Broadcasting Corporation (BBC) network in London in partnership with research bodies and scientists from various British universities and hospitals, and are specified in the bibliographic reference of this work.

### 6.5 Research Participants

The central idea for the purposes of this research was to have the *DPS* athletes in the central role. The researcher in his role as a facilitator sought to instruct the participants of the experiments, providing them with a technical and scientific return based on his reading and interpretation of the collected data. Although all of the stages of the study were performed with both the standing and sit-skiers, it was the wheelchair users that were the main focus of our observations. The observational reports, as well as the questionnaires were separated into analysis categories so that conclusions could be drawn after a review of the literature. The collection of information allowed by the athletes was indispensable for the research and final considerations of the study.

# II. LITERATURE REVIEW

## 1. Nervous System (NS)

The nervous system is formed of the central nervous system (CNS) and peripheral nervous system (PNS). It is responsible for control and integration between the environment and the body systems. Any lesion in the structures shown in Figure 1 can lead to motor, metabolic, behavioural, psychological and social undesirable consequences in the life of the patient.

| | | | | |
|---|---|---|---|---|
| | | | brain | |
| | **CNS** | encephalon------------- | cerebellum | midbrain |
| | | | brainstem---- | pons |
| | | spinal cord | | bulb |
| **NS** | | | | |
| | **PNS** | nerves ------------------ | cranial | |
| | | | spinal | |
| | | spinal ganglia | | |
| | | nerve endings | | |

Figure 1: Structure of the human nervous system.

### 1.1 Central Nervous System

#### 1.1.1 Structure

The CNS is formed by the encephalon (brain, cerebellum, and brainstem), spinal cord and a complex network of connections that link all the parts (Fig. 2 and 3, Annex 1). Information and stimuli from the environment are decoded by our body through our senses that reach the CNS, which in turn stimulates muscles and glands. This is the reason why an accident that involves the spinal cord will interrupt this network of information and the consequences of this will be dependent on the level and degree of severity of the lesion.

**Brain**

The different controls of our body system are located in the two hemispheres of the brain. The cerebral cortex is formed of the superficial grey layer that has a depth of 2-4mm and this is where the neuron cellular bodies are placed that control, for example, body posture for differing positions such as lying down, sitting and standing. Beneath this superficial grey layer lies the white matter, which is basically composed of axons and dendrites. This is where the intellect of a person is placed, along with the processes of thinking, emotions, language and memory.

**Cerebellum**

The cerebellum is located between the occipital lobe of the brain and the brainstem (Figure 2 and 3) and is a part of the encephalon. It is responsible for the maintenance of equilibrium and balance, as well as posture, muscle tone and movement control required for such actions as walking, pedalling and jumping, together with quick movements that are required for activities like running or the playing of musical instruments. It is also responsible for motor learning.

**Brainstem**

The brainstem is made up of the midbrain, pons and bulb, and also contains the sensorial and motor nuclei. The brainstem has an important role in the movement control related to balance and maintenance of body posture. The bulb and pons are responsible for the control of breathing and arterial blood pressure. The brainstem receives information from the cortex and adds the control of balance and posture before the stimulus transmits to the spinal cord and then on to the muscles of the body. However, the upper and lower limb control is performed by the lateral part of the spinal cord.

**Basal Ganglia**

The basal ganglia are a group of nuclei that work in association with the cortex, thalamus and brainstem for the control of complex motor activities that promote coordinated voluntary movements, as well as the control of muscle tone. They are also involved in the planning and execution of proprioceptive information, as well as also being related to emotions, cognition and learning. As an example, a simple throw of the ball during a basketball game summarises the actions in which the ganglia are involved.

**Spinal Cord**

The Spinal Cord is the lower part of the CNS. It comes as an extension of the bulb running from the cranial base to the tip of the sacrum. It is protected by the vertebral column through which it passes. The spinal cord contains the neuronal body of the nervous system that branches off into nerves that will innervate muscles, glands and organs (Fig. 4, Annex 2). The spinal cord is related to reflex movements (Gabbard *apud* Vinagre, 2002), which are part of our biological development from birth, and controls local blood vessels, gastric movements and the excretion of urine. The spinal cord is also involved with voluntary movements that come through the corticospinal pathway, such as walking and anti-gravity movements that are developed in the first years of life, as well as the more primitive actions such as the control of ventilation.

### 1.1.2 Functions

The CNS is responsible for the simultaneous coordination of voluntary movements (e.g. walking and stance) and involuntary movements (e.g. ventilation). It is also linked to our perceptions, emotions and thoughts. The spinal cord gives us the control of walking, anti-gravity muscles, the pain reflex, blood vessels, gastric movements and urinary excretion. The lower level encephalon is responsible for the control of subconscious activities of the body such as ventilation and arterial blood pressure. The upper encephalon is where our consciousness lies and relates to our thoughts, feelings and emotions, as well as the storage of information and the network of communication between them.

## 1.2 Peripheral Nervous System (PNS)

The PNS is formed by nerves, ganglia and receptors (structures responsible for the senses). It is divided into the somatic (sensorial) and autonomic (vegetative) nervous systems that are responsible for the control of voluntary actions and basic functions, respectively. The sympathetic and parasympathetic nervous systems constitute the autonomic nervous system that regulates the action of the organs and glands that maintain homeostasis. It is believed that the weakening of the autonomic nervous system, even though associated with other causes, increases the risk of cardiovascular diseases in Spinal Cord Injury (SCI) victims.

### 1.2.1 Structures and Structure Functions

**Nerves**

The PNS is formed in part by the cranial nerves (12 cranial nerve pairs in the encephalon) and the spinal nerves (31 pairs of nerves in the spinal cord). The nerves are the fundamental physiological units of the PNS (Machado, 2005). They originate in the two main parts of the CNS: the brain and the spinal cord (Fig. 2, 3 and 4). The afferent fibres (sensitive fibres) of the neurons are responsible for transmitting neurological impulses from the organ to the SNC, whilst the organs receive impulses via the efferent nerve fibres (motor fibres) that control the skeletal muscle actions. There are also mixed nerves that have properties and functions of both fibres simultaneously (Jochheim & Stohkendl 1973).

**Receptor Organs**

Receptors are the organs composed of specific cells that capture and transform chemical and physical energy into electrochemical energy. They are specialised systems capable of reading and interpreting the internal environment of the body and the external environment with which the body interacts. They are classified as external receptors, internal receptors and proprioceptors (chemoreceptors, photoreceptors, thermoreceptors and mechanoreceptors) in accordance with the nature of the stimulus. Figure 5 represents the stimulus from the receptor organs to the CNS, which receives processes and sends information that allows an appropriate reaction to different stimuli coming from either the body itself or the environment.

| | | | | |
|---|---|---|---|---|
| | | Processing CNS | | |
| | Sensorial system (afferent fibres) | | Motor system (efferent fibres) | |
| Receptor organs | | | | Responses to the internal and external environments |

Figure 5: Flowchart presenting the path of a stimulus to and from the CNS.

**Nerve Endings**

Nerve endings exist in the extremities of the motor and sensitive fibres. The motor end plate is a typical example of the ending of a motor fibre, whilst the sensitive fibres are very specialised structures that receive chemical and physical stimulus from within the body itself or from the body surfaces. In the skin and mucous membrane there are specialised receptors for heat, cold, pressure and touch, while the pain sensations are perceived by free terminal nerve endings.

## 2. Vertebral Column

The vertebral column is the longitudinal central organ in our body (Fig. 6 and 7, Annex 3). It receives and distributes high levels of static and dynamic forces and has the function of protecting the spinal cord that passes inside it through the spinal canal, and the spinal nerves that emerge from it. (Xavier, 1998). The lumbar region plays an important role in the support of the upper body in the seated and standing positions. Indeed, the body support in any posture is a consequence of a network of several structures, such as the vertebrae, ligaments and muscles. In the same way body movements such as flexion, extension and rotation of the trunk are also related to this complex system.

A normal adult vertebral column that has no major postural deviations has four natural convex curves: two anterior curves (lordosis) considered as secondary curves, and two posterior curves (kyphosis) considered primary curves (Fig. 8, Annex 3). The equilibrium between the physiological curves of the column and the forces supported by the intervertebral discs is essential for the health of the locomotor system of the individual throughout their life.

The intervertebral disc is composed of two parts: the nucleus pulposus and annulus fibrosus that are situated on the periphery of the disc. The intervertebral disc acts as a hydraulic system absorbing the shock of any imbalance or pressure and allowing functional movement (Rocha, 2008). The nucleus pulposus is formed of a gelatinous type substance made up of 88% water, with this being essentially mucopolysaccharides and collagen fibres that provide resistance to its structure. There is no vascular supply or innervation to it, and its nutrition is made through the reabsorption of water with polysaccharides (Kapandji, 2000).

Throughout the course of the day gravity acts on our body, especially in the seated and standing positions, squeezing the water contained in the gelatinous substance of the nucleus, decreasing the height of the disc. This process of dehydration and rehydration of the disc that happens during the life of a person gradually reduces with age, decreasing the mobility and shock absorbing capacity of the vertebral column. (Kapandji,2000). The reduction of this process is even more pronounced in a person confined to a wheelchair as they stay in the seated position for long periods and gravity acts more intensely/continuously on the vertebral discs, accelerating the damage to them.

Nachemson and Elfström (*in apud* Rocha, 1999) studied the effect of four body positions on the intervertebral disc internal pressure between L3 and L4, assuming that the disc pressure in the orthostatic position was 100%. In the supine position the pressure was 24%, in the seated position maintaining the trunk in the normal upright position it was 140%, and in the seated position with the trunk bent forward the pressure was 190%.

## 2.1 Vertebral Column Injury

A vertebral column injury can be related to fractures, dislocation of a vertebra or vertebra joint, lesion of the cartilage or rupture of ligaments, and lesions of intervertebral discs, the spinal cord itself or its nerves. Fractures of the lumbar and thoracic vertebrae are more common than cervical fractures. However, lesions in the cervical column can lead more often to neurological complications than lesions in the lumbar or thoracic column. (Xavier *et al*, 1998).

There is a loss of function when the spinal cord is damaged, such as a loss of mobility and sensitivity of the legs, arms or trunk. The SCI can be complete (paralysis), where loss of function takes place below the level of injury, or incomplete, which causes a relative loss of function. It is not uncommon to have the damage extending to the respiratory, intestinal, urinary and sexual systems. The causes of SCI can be direct or indirectly related to many things, such as car crashes, guns shot wound, falling from a height and accidents in sporting events, among others. When an SCI occurs, there is an oedema of the spinal cord which can lead to consequences in many parts of the body. The oedema may begin to subside after some days or weeks and this initial damage may be reversed. In some cases when the spinal damage is slight, people with SCI can regain some functions even years after the lesion occurred.

The SCI consequences will depend on the type and level of the lesion. In a complete SCI, both sides of the body are equally affected. In very serious lesions where there is a huge impact on the vertebral column, many signs and symptoms can happen: arterial hypotension, bradycardia, heart failure, ventilatory problems or failure, vascular insufficiency and a lack of heat regulation. In an incomplete SCI, the person can retain some level of functioning below the level of the lesion. In such cases, the person may be able to feel part of the body that cannot be moved or might be able to move one limb more than the opposite one, or can maintain the control of movements to one side of the body and not the other.

## 2.2 Complications caused by Spinal Cord Injury

When damage to the spinal cord is as a result of an accident, a physical and psychological trauma happens, which could in itself be a topic for another investigation. This work presents the principle complications related to the volunteers being studied, although many other physical complications and diseases can affect someone after an SCI. It is important to emphasise that any lesions in a paralysed limb will present a long process of healing, regardless of the severity of the lesions.

### 2.2.1 Breathing Dysfunction

Individuals with an SCI involving the upper part of the body (above T4) are at risk of developing progressive breathing dysfunction over the five to ten years after the accident as their breathing pattern will be constantly altered. An SCI below T4 is less likely to have breathing complications but it can occur later on as a consequence of the existing lesion.

The ventilatory mechanics is primarily a function of the intercostal muscles, abdominal muscles and diaphragm, with the latter being directly related to the tidal volume. The deep breathing action, such as when coughing, is done by the intercostal muscles and the abdominal muscles. After an SCI the diaphragm becomes overloaded as the other muscles are either less active or inactive, which results in partial efficiency of these movements. This can lead to acute complications for those individuals who have suffered an SCI as for example, an inefficient coughing action can lead to pneumonia.

### 2.2.2 Cardiovascular Disease

Cardiovascular disease is one of the principle long term risks for people with an SCI. These individuals are generally more sedentary, which increases the possibility of cardiovascular diseases in comparison to the general population. The circulation is classified as hypokinetic, which reduces the cardiac output (CO) for a specific oxygen consumption ($\dot{V}O_2$), increasing the arteriovenous difference of oxygen and reducing the stroke volume (SV) (Nascimento and Silva, 2007). According to Sampaio *et al*. (2001) there is an accumulation of blood in the paralysed areas of the body due to the inefficiency of muscle pumps in keeping an adequate venous return. This in turn reduces the stroke volume, which explains the increase in heart rate to maintain the same cardiac output.

### 2.2.3 Deep Vein Thrombosis (DVT)

The changes in the neurological control of the blood vessels can lead to other important complications of the circulatory system with the worst one being a pulmonary embolism, which causes an interruption of normal blood flow to an area of the lung. This blockage of a pulmonary artery or one of its branches is in general a consequence of a DVT, which is the formation of a clot in a deep vein that is subsequently released and travels to the lung vascular system. This kind of complication affects the victims of SCI in the initial phases of rehabilitation, especially when the legs are affected. The risk of DVT is proportional to the period of immobility, which in the case of someone confined to a wheelchair is a very long time.

### 2.2.4 Pressure Ulcers

Victims of SCI have skin lesions that are known as pressure ulcers or sores in parts of the body such as the ischial tuberosities, trochanters in the hips and iliac crests, as well as the lateral malleolus of the ankles and heels (www.manualmerck.net). This rupture of the skin results from alterations to the skin elasticity and to any prolonged pressure on a bony structure that is in general prominent. A good example of this is someone seated for a long time in a wheelchair, which decreases the blood flow to the skin and causes irritation to these pressure points. These vascular alteration are also associated with muscle loss, both contributing to the loss of the ability of the skin to deal with localised pressure and in some cases this can lead to the necrosis of the skin tissues (sloughing).

### 2.2.5 Osteoporosis and Fractures

The loss of bone mass that occurs in osteoporosis makes the bone more susceptible to fractures, especially in areas that must withstand the weight of the body, such as the hips, spine and wrists. Gravity, the body position in relation to the action of gravity, and the impact of an activity are essentials for the constant development of bone mass.

The majority of people with SCI develop osteoporosis. There is a significant loss of calcium and phosphorous in the bones of a paraplegic patient due to the absence or severe restriction of leg movements, which makes the bone structure weak and fragile.

It is important to emphasise that as the legs are no longer used to support the weight of the body, there is an overload on the vertebral column, even though the physiological curves of the column will be in a process of modification to sustain and retain the body mobility.

Even today, there exists no means of reversing osteoporosis once it has become established and unless preventative measures are taken (exams), it will continue to gradually advance until there is bone breakage. The disease progresses slowly and rarely presents symptoms before a spontaneous fracture occurs. A bone with osteoporosis will take much longer to repair than an unaffected bone.

### 2.2.6 Spasticity

Victims of SCI that have the nerve cells affected below the level of the lesion can also suffer some motor problems, called spasticity. This is characterised by an increase in muscles tone (hypertonia), and hyperreflexia, although all the mechanisms involved are not yet fully understood by the scientific community. The lesion of the peripheral nerves cells causes the opposite with hypotonia, hyporeflexia or areflexia. Spasticity affects the posture and daily activities, and also limits the movements and coordination of the affected members. This is one of the most common and incapacitating problems that affect individuals with CNS lesions (Leitão, 2006).

Pain, stretching or other body sensations are transmitted to the spinal cord. In people with SCI it can be seen when the muscles are excessively extended or when there is something irritating the body below the injury. As there is no longer a nerve connection between the affected region and the brain, the normal sensations generated cause the muscles to contract or generate spasms. In a person who is not able to perform a regular range of movements, it leads to a decrease in muscles and joints flexibility, and in some cases it can cause severe spasticity, whilst in other cases the spasticity might not even be present.

### 2.2.7 Neuropathy

Neurological pain happens in only a few cases of individuals with SCI, but when it does occur the symptoms are very prominent. Reports of pain presented by patients are diverse, although the pain in the nerve itself is described as very acute or like having electric shocks. In exceptional cases the patient describes it as a pain that irradiates from the lesion area in a specific pattern or even as a 'ghost' pain that is related to the lesion, to the nerve itself, or to the spinal cord.

### 2.2.8 Autonomic Dysreflexia (AD)

Autonomic Dysreflexia is a syndrome present in every person that has SCI at the level of the sixth thoracic vertebrae (T6) or above, and is expressed by excessive action of the sympathetic system in the absence of parasympathetic activity. Stimulus causing pain or discomfort below the level of the SCI can cause dysreflexia, which is related to a disconnection between the body below the level of SCI and the mechanisms that control blood pressure and other cardiovascular functions. This can lead to very dangerous levels of arterial blood pressure. As an example, the blood vessels below the level of a lesion can contract and the body responds by vasodilating the vessels above the lesion, causing redness of the skin, sweating and occasionally, shivering. Symptoms related to the increase of arterial blood pressure, such as headache, eye redness and blurred vision, also can indicate AD. The most common causes of AD are: a full bladder, urinary infection, distension of the intestine, severe constipation, pressure ulcers, contusions, fractures, and side effects of medication.

The main risk of having AD, if not properly treated or controlled, is related to the development of a stroke. This happens because the body attempts to control the arterial blood pressure and this can cause a pronounced reduction in heart rate, a combination that can lead to a vascular cerebral accident (VCA) and its potential consequences, including death. AD can happen during medical exams or procedures and for this reason they should only be performed by trained staff and carried out under constant supervision.

### 2.2.9 Involuntary Control of the Bladder

The kidneys are responsible for the excretion of the waste and water present in the blood, in the form of urine. The bladder, which is made up of muscle tissue, stores the urine until the moment that it will be eliminated. The act of urination is controlled by the voluntary and by the autonomic nervous system. The urinary tract works in a synergic way. When the bladder is full it contracts itself to initiate emptying. The sphincter of the urethra relaxes to allow the passage of urine through, and the opposite happens when the bladder is empty. In both situations messages are sent to the brain that can respond or not with nervous impulses to the urinary tract. Therefore, the contraction of the bladder is voluntary and the control of the sphincter is involuntary. If this coordination between the bladder, the sphincter and the urethra does not take place in a proper manner, some complications of the urinary tract may occur.

The majority of people with SCI do not have proper urinary control, with the neurological connection between the bladder and brain, and vice versa, being impaired. According to the level of the lesion, the bladder dysfunction can cause a small amount of urine to be retained, with this subsequently being released involuntarily by spasms of the muscles of the bladder (spastic bladder), more common in spinal injuries above T12. In cases where the lesion happens below T12, the muscles of the bladder become very relaxed and lose the ability to contract, which can cause it to become distended (flaccid bladder). It is possible to have a partial or even a complete recuperation from the SCI if it is incomplete, although this may take a long time. Some techniques can be used to help with bladder emptying, with the most common one being intermittent catheterisation.

When the coordination of the synergic action of the urinary tract is lost, there is a higher risk of developing urinary tract infections. This is because the bladder is weak and cannot release the urine, allowing some to be retained within the bladder, which facilitates the formation of renal stones and the reflux of some urine from the bladder to the kidneys, potentially causing infection and loss of function.

### 2.2.10 Involuntary Control of the Bowel

People having suffered an SCI can present an alteration to their bowel control. This can lead to chronic constipation when the spinal cord injury is high and to bowel incontinence when the SCI is at a lower point.

### 2.2.11 Syringomyelia

Syringomyelia is the enlargement of the central canal of the spinal cord that can happen after a trauma. Magnetic resonance imaging shows the formation of the intramedullary cavities that can occur above or below the area of the trauma. It is less common in victims of SCI (1-3% - American Syringomyelia & Chiari Alliance Project). Its symptoms can occur months or even years after the injury occurs, with the most important symptom being the loss of function above the area of the original spinal lesion. The symptoms that can be perceived are numbness and weakness of the limbs, increased spasticity, and a change in urinary pattern. An advanced syringomyelia state demands surgical intervention with the placement of a drainage tube in the spinal cord.

**2.3 Paraplegia**

Paraplegia is defined as the permanent paralysis of part of the body as a consequence of SCI. It normally affects the thoracic and lumbar areas, resulting in a loss of sensitivity and a loss of movement of the trunk and lower limbs, which prevents walking and makes it more difficult to remain seated. It happens when the peripheral motor pathway suffers a medial interruption and on both sides of the spinal cord.  Infectious diseases such as poliomyelitis or pathological processes such as tumours or abscesses can also lead to paraplegia. Depending on how the movements and sensitivity are affected, paraplegia can be classified as complete or incomplete. In general, the lower the level of the lesion the less the loss of function will be. In cases where pronounced muscle atrophy occurs whereby the fibre muscles are completely destroyed, it is classified as flaccid (Innenmoser, 2012). To the contrary, when the muscles present hypertonia it is considered to be a spastic lesion. It is impossible to reverse the neurological damage when there is a total transversal cut of the spinal cord or when the disability is congenital. There is a possibility of reversal of the lesion by surgical means in cases where there is a compression of the spinal cord, with this being released surgically.

Numerous functional consequences are generated related to the body systems of someone who becomes paraplegic, as presented in 2.2.  In recent decades the health and engineering sciences have endeavoured to come up with efficient solutions for this problem, however, there is currently no effective one that can really reverse the paralysis completely. From the narrower but more realistic point of view of physical education and accepting that the damage caused by the injury is irreversible, each person will require rehabilitative intervention as part of this permanent condition through motor relearning and retraining of the body to interact with mobility aids such as wheelchairs. These measures can improve the life of paraplegic patients, especially where there is constant collaboration with the treatment. It is believed that it is possible to promote a partial rehabilitation of the patient with a program that will contemplate both physical and functional rehabilitation as part of the routine for each one.

**2.4 Dysmelia**

Dysmelia is a congenital malformation of one or more limbs, i.e. the arms, hands, legs or feet. People that have less than 10 fingers or toes have a type of dysmelia called oligodactyly**.** An extreme example is ectrodactyly, also known as split-hand or split-foot malformation where there is an absence of one or more of the central digits of the hands or feet (SHFM; Moerman, 1998). It is also described as "claw-like" where there is only the thumb and one other digit, normally the little finger or the ring finger, but the same situation can also happen with the toes. A large number of defective human genes can cause ectrodactyly.

**3. Anatomy-Physiology of the Seated Posture Secondary to Pathological Processes**

The centre for human equilibrium during locomotion lies in the sacrum that connects the lower limbs with the pelvis and to the trunk through the spinal cord (Kapandji, 2000). Remaining in the seated position as occurs due to paralysis and loss of function in the lower limbs as a result of an SCI means that the body posture of the individual becomes modified and the centre of equilibrium is shifted to above the sacral area.

A baby that has two primary curves of the vertebral column and is initially unable to either support the trunk while in the seated position or walk, gradually modifies the curves of the column during the first years of development. The lumbar column of a new-born baby is a convex curve, however, as the baby develops and by the age of 13 months this curve has straightened. It will achieve its maximum development by the age of 10 years by which time the lordosis shape will be well defined (Willis, cited by Kapandji 2000). Therefore, the lumbar lordosis is an evolutionary characteristic of the human being and is very important for good development of essential motor functions, such as maintenance of body posture and movement. It is correct to say that the evolution of the species repeats itself in the individual development of each human being.

For some who has become paraplegic and wheelchair dependent as a consequence, a process of regression begins whereby the body posture suffers a constant change in the opposite direction to the natural evolution of a human being. The vertebral column, and more specifically the lumbar region, begins a process of modification of the physiological curves that had previously been developed until the point when the trauma occurred, in order to reassume a straightened or convex posture.

According to Souchard (1984) and Bienfait (1995) from an anatomical point of view, the sacrum and ilium bones are the origin of the posterior muscles of the trunk (anti-gravitational) and these muscles are responsible for supporting the vertebral column in the standing position and also when a person is seated without support. The lumbosacral column in people who are dependent on a wheelchair changes its lumbar-lordosis curve as they stay seated for long time periods. This reduction in the curve of the column also interferes with the spinal, diaphragm and iliopsoas muscle activity, which in normal situations are involved with the maintenance of the physiological curve.

The seated position is considered by Kroemer and Sember III (apud Lueder, 1994) as unnatural. In the paraplegic person, the anatomic posture assumed when seated and associated with the tension of the posterior thigh muscles (hamstrings) leads to a change in the position of the hips, and this promotes a straightening of the lumbar-lordosis (Lueder, Corlett, Danielson *apud* Lueder, 1994). Therefore, it is possible to say that the action of the gluteus and hamstring muscles in the seated position are the main cause of the straightening of the lumbosacral region of the column (Lueder *et al* apud Lueder 1994).

Prolonged amounts of time and a lack of mobility in the seated position in non-paraplegic people cause discomfort and leads to a need to change position (Moraes and Pequini, 2000). The long periods that individuals confined to a WC spend in the seated position and the associated lack of mobility of the legs and hips are also factors that cause side effects, as referred to in research by Moraes and Pequini, although in these situations and especially in extreme cases there may be a lack of pain sensitivity.

Ergonomic studies have been performed with non-paraplegic individuals aimed at measuring the pressure on the íschium, thighs and coccyx in the seated position in order to verify the support effects on the lumbar column and the physiological changes in tissues (Sember III *apud* Lueder, 1994). Bendix apud Lueder (1994) suggest the occurrence of pain as a consequence of the prolonged compression on the intervertebral joints of the lumbar column due to the seated position. From a human movement science point of view, different forms of intervention are sought with the objective of minimising the physiological effects secondary to remaining in the seated position, as this is the body position in which a paraplegic person stays for long periods of time. Such interventions as the evaluation of wheelchair dimensions and conditions in order to test varying ways of promoting lumbar column support, or the checking of seat height and feet support aim to positively affect the quality of life in daily activities (Carriel, 2007). Other ways to increase this would be the verification of the circulatory system response in conjunction with an evaluation of trunk and hip positions in certain sporting, pleasure or daily life activities. (Van Der Woude, 2006).

The reduction, or in more severe cases, the complete loss of the function of anti-gravitational muscles, associated with the effect of body weight on ischial tuberosity and the physiological rigidity of the lumbosacral lordosis causes part of the physical and physiological complications that affect someone with an SCI. Such a person with special needs will need to live with and adapt to the new situation, using preventive measures to enhance their quality of life. Intervention through specific exercises and body movements has the objective of decreasing the degenerative and regressive process and it is an option that most people with an SCI can access. Advances in medicine and physiotherapy, although more advanced than those found in sports science, are not available to people of all social classes.

### 3.1 Important Muscles of the Trunk and Lower Limbs involved in the Seated Position

The principal muscles involved in maintaining equilibrium in the standing position, during walking, or in the seated position without support are the spinal muscles, hamstrings, iliopsoas and the diaphragm (Souchard, 1984; Bienfait, 1995; Vieira, 1998). These muscles will gradually atrophy in a person that becomes paraplegic as they will no longer be used, bringing with it several consequences.

**3.1.1 Spinal Muscles** (interspinous, supraspinous, lumbosacral, long dorsal)

Although the posterior muscles of the trunk present a non-segmented and continuous aspect, (Bertherat, 1986), the spinal muscles in the inner muscle layers of the human body present a great number of origins and insertions than the ones presented as the focus of this study, which originate in the sacroiliac region and give to the column, along with other muscles, support to the trunk and head against gravitational forces (Souchard 1984).

The spinal muscles along the lumbar column and the cervical branch, responsible for head movements and the maintenance of the horizontal gaze develop in opposite directions, with the biggest concentration of branches in its origin, which are gradually reduced as the distances from it increases. This causes a greater concentration of insertions of spinal muscles in the two areas of the column with lordosis curves (cervical and lumbar). Maintaining the stability of the vertebral column and all its curves and movement possibilities is provided by the action of the spinal muscles

**3.1.2 Hamstrings** (biceps femoris, semitendinosus and semimembranosus)

The hamstring muscles are responsible for the extension of the hip. They support the pelvis in the vertical position when the individual is standing, but during the seated position they can remain stable as the balance between the contraction of the anterior and posterior muscles is kept. In the seated position, the hamstrings are taut when the knees are extended but they are less tensed when the knees are flexed and not shortened in either situation.

**3.1.3 Iliopsoas** (psoas major, psoas minor and iliacus)

The iliopsoas is a combination of three muscles and is the most potent flexor of the hips. It has its origin located in the lateral side of the vertebras T12 and L1-L5 and promotes the lumbar lordosis. Over the years, the spinal muscles assume a form caused by the action or lack of action of the iliopsoas (Souchard 1984; Bienfait 1995). The form established from the standing position promotes a physiological rigidity of the spinal muscles, which are considered complementary muscles to the establishment of the lumbosacral lordosis. In the seated position, the spinal muscles that are synergic to the diaphragm during inspiration and to the iliopsoas in the establishment of the lumbar lordosis become less active in the elevation of the ribs due to the constraining presence of the high back of a chair.

The action of the iliopsoas and adductor muscles may be compromised in a paraplegic person depending on the severity of lesion, causing the legs to stay in a flexed and abducted position associated with lateral rotation of the hips. When seated in the WC and with legs comfortably positioned, the maintenance of the stability of posture of the lower limbs is proportional to the ergonomics of the chair. The lack of function of the iliopsoas muscles compromises the stability of the seated position and promotes negative feedback, especially if the paraplegic individual does not follow a specific and continuous program of physical exercise.

**3.1.4 Diaphragm**

The diaphragm is a striated skeletal muscle in the form of a dome which is stretched by a strong ligament from the base of the skull and the cervical column. It is situated below the lungs and physically separates the thorax from the abdomen. It is the most essential muscle for ventilation, but also plays an important role in maintaining an erect posture of the trunk in the standing and seated positions. Some other vital body functions such as circulation and digestion also depend on the involuntary action of the diaphragm. Voluntary actions, such as to create tension when lifting heavy weights, are performed by pillars that are inserted in the lumbar vertebrae and discs, together with insertions of the psoas muscle and the transversus abdominis that pull the lumbar region forward, preserving the lordosis in this area. These attributes are also performed by the diaphragm to prevent posterior impingement of the nerve roots (Souchard, 1984).

The diaphragm is part of a muscle-tendon anterior chain[1] of the body that has its origin in the base of the skull and goes longitudinally to the feet, exerting the static function of suspension (Souchard *apud* Huet, 2003). This structural characteristic gives forms and limits to other structures that are linked to the diaphragm, such as the cervical vertebrae, pharynx, heart and stomach (Bienfait 1995). This network of muscles that support the physiological curves and dynamics of the column are compromised with age, which promotes the rigidity along its extension, although this varies from person to person. This chain is interrupted in a paraplegic person as the lower limbs are paralysed, but the muscle network between the lower and upper parts remain. This shows the interdependence of the two parts since the paralysis affects the maintenance of the posture in the upper part of the body.

### 3.2 Ergonomics of the Seated Posture

Long periods of standing, sitting or lying down become uncomfortable and damage the health of an individual, regardless of whether paraplegic or non paraplegic. (Roebuck 1995; Bendix, apud Lueder, 1994). It impairs blood circulation (Sember III, apud Lueder, 1994; Moraes 2000), besides the discomfort caused by the deformation of the lumbosacral column, the pressure felt over the ischial tuberosity, and the compression caused by a chair seat on the thighs, together with the lack of movement of the lower limbs. Movement and changes in body position are necessary to reduce the deleterious effects caused by prolonged periods of being seated, although this position offers advantages when compared to standing. Physiologically, the seated position presents a lower energy cost and is a better position for the performance of some fine tasks that require more attention (*modus operandi*) or manoeuvres that need high levels of precision, such as to pilot a plane.

It is important to mention the findings based on the electromyography results obtained by Lundervold *apud* Moraes (2000). When an individual sits upright he presents a high level of electrical activity, which results from the static effort of the back muscles and the type of contraction performed by them.

### 3.3 Variations in Body Posture in the Seated Position

An important imbalance occurs in wheelchair dependent individuals between the upper and lower parts of the body, the anterior and posterior regions, and from one side of the body to the other, as they remain for the most time in a seated position. Many posterior muscle fibres are distended and ligaments are stretched in this position, causing vertebral instability and consequent stress on the involved joints (Reinecke *et al.*, apud Lueder, 1994).

[1] The cervical-thoracic-abdominal-pelvic chain or great anterior master chain is described by Bienfait and Souchard of the Schools of Osteopathy and Global Postural Re-education.

The pelvis is in anterior rotation when an individual is seated on the íschium and the lumbar column is in the lordosis position, which requires the work of the iliopsoas and spinal muscles. If the person is bent with the trunk forward there will be anterior rotation of the pelvis and a subsequent straightening of the lumbar column. However, if the erector spinae muscles are inactive, there will be posterior rotation of the pelvis, increasing the kyphosis of the vertebral column. On the other hand if the individual is sat with hips forward and the thoracic column resting against a chair for support, the pelvis will have a posterior rotation and will keep the equilibrium of the trunk through the support of the tuberosities and the coccyx on the seat.

## 4. Human Performance

### 4.1 Cardiopulmonary System

The complex system responsible for respiration has the function of ventilation, perfusion and diffusion of oxygen and carbon dioxide. Within the pulmonary alveoli that are the functional units of respiration, about 250mL of oxygen can be captured and 200mL of carbon dioxide can be eliminated from the blood (Souza, 2006).

Under normal conditions around 4 to 5 litres of blood pass through the heart per minute. The lungs, if needed, have sufficient capacity to oxygenate up to 30 litres of venous blood per minute to meet the needs of the body. Therefore, it is clear that the human lungs have a large reserve that can meet the required conditions during physical exercise (McArdle, 1986).

#### 4.1.1 Pulmonary Ventilation (VA)

Pulmonary ventilation is accomplished almost exclusively by the muscles of inspiration. It begins its cycle when the rib muscles and diaphragm contract, increasing the volume of the chest cavity and reducing the air pressure within, which allows air into the lungs and down to the pulmonary alveoli. During inspiration, the ribs expand under the action of the intercostal muscles, increasing the anteroposterior diameter of the thorax as they move the sternum away from the vertebral column. The reverse happens during expiration, when the anteroposterior diameter of the thorax is decreased. This combined movement of the ribcage produces pressure variations in the airway, creating negative intra-alveolar pressure during inspiration (around -1 mmHg) and positive (around +1 mmHg) during expiration. These values can multiply during forced inspiration, reaching approximately -80mmHg, or nearing a value of +100mmHg during a maximum expiration with the glottis closed. VA has its mechanical cycle ended passively during expiration and with the relaxation of the inspiratory muscles, due to the elastic properties of the lungs, the ribcage and the abdominal structures that compress the lungs and then return to the original position.

Alveolar ventilation is an important part of the pulmonary ventilation process as it represents the velocity that the alveolar air is renewed every minute by the atmospheric air during the pulmonary gas exchange. There is always a difference between the alveolar ventilation and the tidal volume, as part of the inspired air will not reach the alveoli for the gas exchange with the blood. Under normal conditions the diffusion velocity is higher than the flow velocity when the inspired air reaches the small airway path, as the transversal total area of the airways increases and the flow velocity decreases. As such, the concentration of oxygen and carbon dioxide in the alveoli is determined by the alveolar ventilation and respiratory frequency.

Pulmonary ventilation, which results from the respiratory rate (RR) x the tidal volume (VT), can be measured from lung volumes (tidal volume, inspiratory reserve volume, expiratory reserve volume and residual volume) through the use of spirometry. Pulmonary ventilation increases proportionally during exercise with the production of carbon dioxide ($VCO_2$). Spiroergometry allows the measurement of pulmonary ventilation and shows that it increases progressively with the increase in $CO_2$ production until it reaches a maximum plateau. An athlete can reach 200L/min of pulmonary ventilation (Yazbek Jr. *et al*, 1998), although this figure can be diminished due to cardiopulmonary limitation if the athlete has heart or lung diseases, or has suffered a spinal cord injury.

#### 4.1.2 Response to Exercise

Cardiopulmonary exercise indicates that the cardiopulmonary system is working as an integrated unit that receives, releases and performs the gas exchange, giving energy and allowing an individual to perform their work (West, 1971). Other than the consequences that affect the motor system of a person, a SCI can also interfere with the performance of the cardiovascular system by reducing venous preloading, impairing inotropic and chronotropic responses and increasing afterloading. The performance of the respiratory system is limited by muscle weakness and associated with poor postural control (Shephard, 1989; Davis, 1993).

There is a strong tendency in paraplegic people for the blood to remain in the large veins of the lower limbs. If the spinal lesion happens at the height of T10, it can affect the sympathetic nervous system of the cardiopulmonary system and cause paralysis of the intercostal and abdominal muscles, which in turn can lead to loss of venomotor control of the legs. This can also happen to the arms and upper limbs if the lesion occurs at T5 (Davis, 1993). However, a high lesion can also diminish vital capacity and weaken the intercostal and abdominal muscles innervated by the segments from T1 to T11, and the diaphragm by the phrenic nerve that lies between C3 and C5. This can lead to impaired respiratory flow, an increase in respiratory work and an accumulation of secretions, all of which can combine to cause respiratory failure, the main cause of death in people affected by SCI (Sartori and Melo, 2002). In addition, the pumping action of the calf muscles that will normally help with the venous return to the heart will cease to happen. As a consequence, there is a tendency to reduce the volume of blood in the central part of the cardiovascular system, since there is less preloading of the ventricles (Shephard, 1994).

Another difference seen between able bodied people and those affected by an SCI is that the circulation can be hypokinetic, which reduces the CO (Cardiac Output) for a specific oxygen consumption ($\dot{V}O_2$), which in turn increases the arterial venous difference of $O_2$. The difference in arterial venous oxygen for an athlete in a wheelchair can be greater than that for a non-disabled athlete when both perform maximum exercise with the upper limbs (Lakomy, 1987). This suggests that there is muscle hypertrophy and allows a greater release of oxygen for a specific cardiac output, in spite of a significant reduction in stroke volume. Moreover, the paraplegic person also has a tendency for hemoconcentration during prolonged exercise due to the stagnation of blood in the lower limbs. This causes a very slow increase in the oxygen consumption in the steady-state exercises of SCI sufferers (Shephard, 1994). According to Sampaio *et al.* (2001), stroke volume decreases with an accumulation of blood in the lower limbs due to the inaction of the muscle pumps of the legs, and this explains the increase in heart rate in order to keep the same cardiac output.

Pulmonary ventilation in a paraplegic person is high in relation to oxygen consumption and therefore, respiratory problems can be caused by a significant deficit of oxygen and the accumulation of lactate and hydrogen ions. The physiological adaptations driven by physical exercise are desirable and improve the quality of life for people with SCI because it decreases lactate and resting heart rate, which increases endurance.

According to Nascimento (2007), aerobic training and endurance training through sports such as swimming can positively affect the cardiopulmonary parameters ($\dot{V}O_{2max}$, HR, CO, SV, respiratory capacity), with this bringing greater improvements for paraplegics than tetraplegics (Cowell, 1986).

**4.1.3 Maximal Consumption of Oxygen** ($\dot{V}O_{2max}$)

Oxygen consumption increases proportionally to the work load (Wasserman, 1975; Silva, 2002), with the $\dot{V}O_2$max being the highest value of this variable. The total energy production during maximum exercise is determined predominantly by aerobic capacity as well as by a variable anaerobic component, which will be inversely proportional to the time of effort. Therefore, the performance of long term activities is directly related to $\dot{V}O_{2max}$ (Åstrand, 1986). The $\dot{V}O_{2max}$ has been used to predict aerobic capacity for exercise with a duration above 2-3 minutes, when there is a predominance of aerobic energy production (Åstrand, 1986).

The absolute $\dot{V}O_{2max}$ values are in litres or millilitres per minute (L/min, mL/min) and the relative $\dot{V}O_{2max}$ is in millilitres per minute per kilo (mL/min/kg). The latter is used when comparisons are needed as it considers the absolute value and the body weight of the individual. However, the interpretation of the oxygen consumption values in relation to body weight should be performed with caution in people with deficits of the lower limbs, such as with atrophy, paraplegia, absence of a limb or amputation, as there is an imbalance of the body mass that can affect the results (Bergh, 1987). Nevertheless, this discrepancy can be even greater if the absolute value is used. In this case, if it were possible to perform the test with the lower limbs, the findings would show an increase in 20% to 30% since the muscle mass volume would be larger (Miles, 1989).

In tests where the maximum effort is reached over the course of progressive stages, a plateau in oxygen consumption will be achieved, meaning that the aerobic system is at its maximum and that the energy will then be given by the anaerobic system. This plateau is not easy to be seen in adults, the elderly, sedentary, sick and handicapped people. In these situations when there are limiting motor factors, the highest value of $\dot{V}O_2$ found and used as a reference is called the $\dot{V}O_2$ peak (Sawka, 1983/1986). According to Shephard, Kofsky *et al.* (1986) published the aerobic power norms in relation to age, gender, and the performance of sports in a wheelchair, that were based on submaximal tests performed through the use of an upper-limb cycle ergometer.

### 4.1.4 Integration to the Specific Sport

The evaluation of cardiorespiratory performance for paralympic athletes provides a framework of information for sports scientists and athletes, enabling individuals with disabilities to develop new physical activity and training routines.

In the particular case of people affected by spinal cord injury, the peak $\dot{V}O_2$ is used as a reference for the analysis and comparison of their results as the criteria for reaching $\dot{V}O_{2max}$ is difficult to attain. As such, it would be interesting if the tests proposed for the evaluation are in keeping with the movements required for the actual sport itself. The quality of the results collected and the perception of the evolution of $\dot{V}O_{2max}$ will be optimised by ergometry undertaken while the athlete conducts movements and uses muscle groups appropriate to their specific sport.

Whilst it is not always possible to have exact tests specific to all sports, research centres do seek to provide elite disabled athletes, and indirectly disabled non-athletes, with a way to conduct evaluations and protocols that are as precise as can be in the given circumstances, as with the tests for this particular research that uses spiroergometry (direct method). The assessment of maximal oxygen uptake was undertaken, together with the direct methods of measuring $\dot{V}O_2$, the respiratory exchange ratio (RER), maximal or submaximal HR, exercise intolerance and blood lactate levels.

According to Bhambhani (2003), the ideal protocol for ergometric testing carried out by athletes with an SCI (individuals with low level paraplegia) is one that begins the test with 'zero' Watt and systematically increases loading of 20-25 Watt/min until voluntary fatigue is reached. This protocol is suitable for identifying the lactate threshold and peak $\dot{V}O_2$. Subjects with injury below T6 that retain full innervation of the myocardium should also be able to reach their predetermined $HR_{max}$ during exercise of the upper body. However, because of the high level of paralysis of the trunk muscles, it may not be possible for them to achieve their age-related predicted $HR_{max}$.

In general, it can be said that the $HR_{max}$ and peak $\dot{V}O_2$ achieved during exercise is inversely proportional to the level of the lesion. Higher values of arteriovenous oxygen difference and peak $\dot{V}O_2$ are found for those with an injury below T10 in which the trunk musculature remains viable for exercise above the waistline, as compared to individuals with an SCI at a higher level where the ability to use these muscles is compromised. Cardiorespiratory responses normally result in higher peaks for those people having suffered an incomplete lesion, regardless of its level. Results encountered in simulated race competitions indicate that recreational athletes with paraplegia exercise at a level of 95% of their peak $\dot{V}O_2$ and HR values (Bhambhani, 2003).

**4.2 Motor Learning**

Many studies stress motor learning as being a key element in the comprehension of movement and the processes linked to it. The author of this present study has previously researched the process of learning and motor development of babies in a water environment (Vinagre, 2002) and some of the fundamental ideas from this work became essential for understanding the physical evolution of Paralympic alpine ski athletes.

According to Schmidt and Wrisberg (2001), motor learning involves changes in internal processes that determine the capacity on an individual to produce a motor task. The level of motor learning of an individual increases with practice and can be assessed by the observation of relatively stable levels of motor performance of a person. It is necessary for people with special needs that have to learn or relearn motor activities to be exposed and submitted to practice. Through this exposure they increase their potential for performing the desired actions, even if only partially, and there is the possibility of improvements in movement and in the quality of performance with numerous repetitions of the act.

For professionals who work with human movement, whether from a preventative or rehabilitative perspective, one of the ways of assessing the motor learning of a person is to observe from a motor point of view how they perform a requested task. In the case of the *DPS* athletes, the levels of motor learning they have for Alpine Skiing can be accurately reflected by an evaluation of their performances in the proposed wind tunnel tests and their ability to reproduce the required postures at various speeds in a stable manner.

Through both the traditional learning methods together with the emerging proposals, the scientific community has researched new alternative processes of teaching/learning that also enable a greater integration between theory and practice in the training of professionals from the sciences within an interdisciplinary spectrum, through active learning based on competencies. According to Combs as cited by Schimidt e Wrisberg (2001), efficient problem resolution is learned by confronting events and defining problems, and by seeking, experimenting, trying and researching effective solutions. In this way, the approach to the motor and performance learning is based on the problem.

For able bodied people, the motivation and self-learning of motor activities determine their availability for learning the movements to be executed, and help improve the quality of the exercise performed. In the case of people with special needs, these skills become even more evident, due to the uniqueness of each disability. The number of people that represent this segment in society may be small, as is still the case within Brazilian society. The process of relearning some movements that have either been compromised or lost for some individuals is a slow process as they must adapt to this new reality and adjust their lives and daily activities. In addition, these people may not have the opportunity to observe others with similar physical deficiencies and often cannot count on a network of support. The principles related to the learning of a movement are similar for everyone, but the physical differences and capacities of each person should be taken into account, respecting their individual learning curves.

The victims of spine trauma, stroke and congenital malformation must establish a new relationship between their mind and their altered body capacities, which requires a completely new process of motor learning and muscle joint development. This will help to create a new motor vocabulary in their daily activities, which can require a significant effort.

It is essential that the professionals who will deal with these situations know *with whom* they will be working, *what* the disabled person wants to learn and *where* this learning process will happen. It is believed that to obtain good results in these situations it is fundamental to answer these three basic questions at the beginning of the work. For sports scientists (Jonath & Krempel, 1981), the learning process, the evaluation itself, and the information relevant to this process affect the structure of the training with the aim of creating advantages for the athletes in competitive situations.

It is very clear in the current study ***who*** the person is that is being helped, ***what*** the task is that they wish to perform, and ***where*** the task that the person wishes to perform will take place. In addition, the subjects of this study are very committed to improving their performances in Alpine Ski competitions and during the actual races, under conditions where there are additional time pressures on the performance of the athletes.

Most of our actions, such as locomotor and fine motor movements, involve body posture as an important component and these are all interlinked. This is important for the professionals that work with movement, who should always consider the postural component of motor control. In physiotherapy, for example, the head, neck and trunk are the initial points of treatment. This premise applies very well to this study.

Results of studies related to the basis of performance skills and the factors that influence a person's ability to learn these have been extremely useful for movement professionals, as successful strategies for teaching specific skills and daily living activities can be incorporated into their motor vocabulary, generating medium to long term therapeutic strategies that are efficient but low cost.

The manner in which individuals interact with the environment during skilled movement, or depending on the complexity of the task, is also found in the literature on motor learning (Jonath & Krempel, 1981), which allows us to establish evaluative constructs for human performance and to see how they can influence the learning and performance of new skills.

### 4.3 Sport Performance Structure targeting Paralympic Alpine Skiing

The performance structure must continue to be analysed and developed when considering an evaluation of the learning profile for movement aimed at Alpine Skiing for people with disability. This can help develop other applications that will benefit this sport, as well sport science as a whole. The performance structure of a sport is generally defined as "the internal structure of the sports performance of certain factors (elements) and their interaction" (Schnabel & Thieß, 1986). The achievement of each sport depends on several conditions (factors). External factors include environmental conditions (or premises where the sport will be performed), altitude and climate, together with the equipment to be used. Personal factors include psychological performance and behavioural qualities, tactical ability, coordinative-technical skills, conditional capacities and constitutional qualities, on which this study was focused.

At an abstract level of evaluation, each of these factors of personal performance provides access to and the possibility of development of different human capabilities. The Table 1 (a-e) show details of these areas of development. However, in order to make a factual evaluation for each of these elements, it is first of all necessary to correctly fit the evaluative options to the 5 distinct factors. The elements found in Table 1 (a, b and c) are evaluated at the level of the sensory-nervous systems of reception, processing and storing of information (cognitive, motivational, emotional, volitional aspects). The coordinative-technical capacities and skills (Table 1c), as well as the conditional capacities (Table 1d) fall into the possibilities of evaluation of the sensory-motor system (neuromuscular system).

**Table 1 (a-e): Personal Factors and their Respective Capabilities**

| **a. Psychic performance and behavioural qualities** |
|---|
| Knowledge<br>Intellectual ability<br>**Perception capacity**<br>Imaginary capacity<br>Motivation<br>Emotional capacity; temperament |
| **b. Tactical capacities** |
| **Capacity of Perception of a situation**<br>Anticipatory capacity of a situation<br>Fast situation-related decision making capacity |
| **c. Coordinative-technical Capacities and Skills** |
| **Coordinative capacity**<br>Motor (sports technical) skills<br>Flexibility |
| **d. Conditional (energetic) capacities** |
| Strength capacity<br>**Endurance capacity**<br>(Speed capacity) |
| **e. Constitutional Qualities** |
| Physique (proportion, mass, flexibility, structure of muscle fibres)<br>**Loading capacity (mechanical)** |

The elements highlighted in bold in the 5 parts of the table are those elements that were addressed in this study.

The elements in Table 1d are those that have the most concrete evaluative possibilities. In this case, the evaluative possibilities of the cardiopulmonary system, energy metabolism, as well as the locomotor and the sensorimotor systems can be evaluated by these factors. The last aspect presented of constitutional qualities (Table 1e) can include evaluations from a morphological point of view.

Based on a specific sports performance structure, it is possible to develop *a posteriori* predictive instrument, consequent organisation and methodological project of training. In order to develop a model of the athlete performance structure for a sport, the internal factors must also be taken into account, as presented by Harre (1976). This model contains factors that are directly and indirectly related to the study in question, as shown in Figure 9. According to Schnabel and Thieß (1986), athletic performance is the unit that includes the execution and outcome of a sporting activity, measured and/or evaluated by socially determined norms that were previously discussed and agreed. The factors from this diagram that relate to this study are highlighted in dark blue.

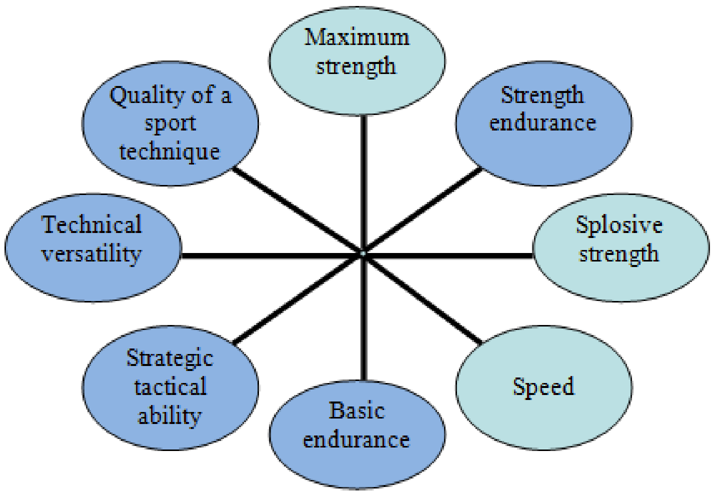



**Figure 9:** Internal factors presented by Harre (1976)

According to the general model of sport performance developed by Schnabel (1977) the maximum performance initially depends on multiple factors (technical, coordination, athletic conditioning, tactical, physical and ideological). The performance would also be dependent on external factors, such as environment, the training personnel, sports officials, federations and terms and conditions, among other factors both in the general performance model (Schnabel, 1977) and in the sports specific model for Alpine Skiing  (Barth & Brühl, 2005).

Schnabel and Thieß (1986) define ability as being a prerequisite of individual performance for certain activities, characterised by the level and quality of psycho-physical processes. A brief definition of skill (automated component of human activity) and motor skill (automated component of a motor activity developed during the processes of learning and practice based on motor abilities) are also presented by the same authors so the structure of physical abilities in relation to the phases of development can be understood.  For example, coordinative abilities are developed in *early-age abilities* at an age range of between 4-5 years, whilst in *late-age abilities* the aim shifts to starting work focused on anaerobic endurance and maximum strength capacities from 11-12 years of age. However, the aerobic endurance (basic endurance) and strength endurance abilities, that are considered neutral capabilities, can and should be worked on from the age group of 4-5 years.

The coordinative abilities can even be presented as general and special, as shown by Weineck (2005). The overall result is a multiple movement in training for different sports. They also arise in distinct areas of everyday life and sport so that the preferred tasks can be initiated rationally and productively. The special coordinative abilities are formed more within the limits of the respective competitive discipline and are characterised by variations in technique for the sport in question.

The main coordinative capacities according to Meinel and Schnabel (1987) considered to be superior are those of regulation, adaptation and motor learning, but bringing together the derived coordinative abilities that are of association, differentiation, equilibrium, orientation, rhythm, reaction and change. According to Weineck (2005), the more complex a movement of a motor sequence, the greater the importance of the coordinative capabilities and consequently, the faster new and more complex movements can be learned. Applying this to the sport under study is to say that the more developed the coordinative capacity of the athlete, the greater the chance will be of responding effectively to prevent a fall, collision, accident or injury when faced with an unexpected situation. The level of coordinative ability affects the general and specific learning capacity, the time necessary for learning sporting techniques, the quality of execution of movements, the quantity of energy used for such movements, the degree of use of physical conditioning for the sport performance, the pace of learning new movements adapted for an altered mobility reality, and along with other performance factors, the limits of sports performance for a paralympic athlete.

Figure 10 presents an adapted diagram from Wippermann (2012) of the performance structure for Paralympic Alpine Skiing created by Jonath & Krempel (1981) and the extent of the form of performance structure currently directed at this sport, can be seen.

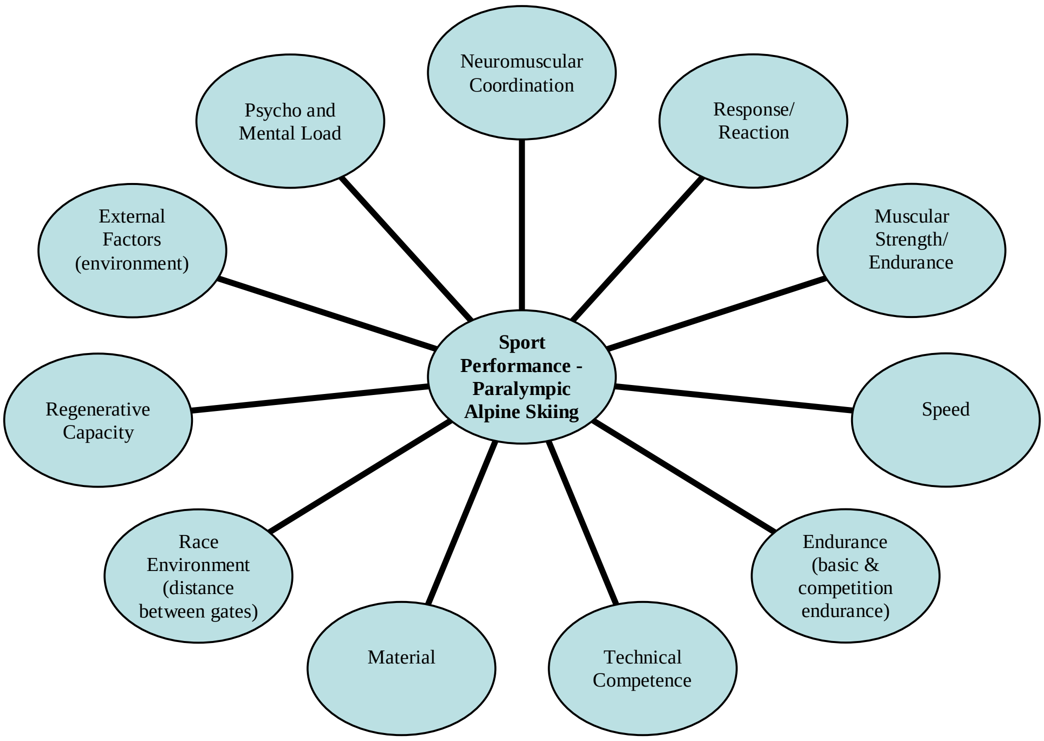



**Figure 10:** Performance structure - Paralympic Alpine Ski, according to Jonath & Krempel (1981), as presented in the thesis of Wippermann.

## 5. The Experiment Environment

### 5.1 Technical Options

Three different methods were used for the evaluation of members of the German Paralympic Alpine Ski Team. All wheelchair athletes were subject to spiroergometry testing using their own wheelchairs on a treadmill with specially adapted pulley system, whilst a stationary bicycle ergometer was used to evaluate the stand-ski athletes in two different manners.

**Table 2: Frequency and Distribution of the Tests.**

| Phase of Study | Treadmill Spiroergometry | Bicycle Ergometry | Bicycle Spiroergometry | Aerodynamic Evaluation |
|---|---|---|---|---|
| Experiment I | 4 | 2 | -- | -- |
| Experiment II | -- | -- | -- | 7 |
| Experiment III | -- | -- | -- | 5 |
| Experiment IV | 4 | -- | 1 | -- |
| Total | 8 | 2 | 1 | 12 |

The first experiment session saw the standing volunteers perform an ergometric stress test using the bicycle, and at a later second evaluation session one of the standing volunteers also took part in a spiroergometry test, again using the bicycle. All athletes were involved in the wind tunnel aerodynamics testing that was conducted for both campaigns. The frequency and distribution of the tests performed can be seen in Table 2.

#### 5.1.1 Spirometry

Spirometry is a technique aimed at evaluating lung volume and capacity, and from it the parameters for the detection of respiratory disease. Gasometers of two different types can be used for this purpose: Closed circle (Collins gasometer); Open-circuit (Air-Shields gasometer, Monaghan gasometer). The spirometry in this research was carried out in conjunction with ergometry resulting in more specific functions, however, we would like to present three measures of volume that can be achieved using this technique when it is undertaken in isolation.

The vital capacity (VC) of the lungs can be ascertained by measuring the maximum volume of air that can be expelled from the lungs after inhaling as deeply as possible. The forced expiratory volume in 1 second (FEV1) is the maximum volume of air that can be forcibly exhaled from the lungs in 1 second after starting from a position of a maximum inspiration or total lung capacity, and is calculated from a paper trace. The maximum voluntary ventilation (MVV) is the largest volume of air that can be breathed by inhaling and exhaling over a given time period. It is determined from a person breathing as quickly and deeply as possible for 12 or 15 seconds, and from that figure the volume for 1 minute can be calculated.

#### 5.1.2 Ergometry

Ergometry as a means of diagnostic evaluation can be applied through the use of different pieces of ergometric equipment such as treadmills, bicycles and stair climbers (McArdle, 1998). It has provided good results as an application method and in terms of the safety of athletes being assessed, and volume of training adopted. It is not as complex as spiroergometry and has a low operating cost.

Åstrand, cited in Sousa (1997) says that "*ergometry is usually associated with measurements and prognosis of capacity and efficiency of the cardiorespiratory system, because it reflects the individual's ability to engage large muscle groups in vigorous activities that last a few or many minutes*".

Ergometry was used for the evaluation of the *DPS* athletes during the first experiment session only and involved just the stand-ski athletes, whilst considering the possibility of establishing a more evaluative method during the course of the study. An exercise protocol with a progressive workload, known as the Hollmann protocol (Hollmann, 1997), was adopted with the load being increased every 3 minutes until either fatigue prevented their continuance or the athlete requested the termination of the test. The calculation of oxygen consumption during the exercise was performed through equations with time, mass and heart rate being taken into account when working out the figure for $\dot{V}O_{2max}$, thus it is an indirect method (Stein, 2003, Neder, 2001).

**5.1.3 Spiroergometry**

Spiroergometry is made up of the two components ergometry and spirometry, and provides a means of evaluating physical fitness through physiological variables. It has shown accurate results with respect to the cardiorespiratory performance of the athletes evaluated. This is a direct method with the determination of oxygen consumed during the exercise being made directly from the analysis of the respiratory gases. This analysis can be performed in a closed or open system. The method used for this research is an open system, with the oxygen consumption being calculated on the basis of measures of volume (expired minute volume - VE) and the percentages of inspired and expired gases ($F_EO_2$ and $F_ECO_2$), and it may be used throughout the range of physical activities. By using the technique of breath-by-breath analysis for this study, it was possible to examine reactions under dynamic stress, both on the treadmill and the bicycle ergometer.

This methodological option requires that greater care be taken in preparing and conducting the test procedures to ensure the accuracy of the results. The software (Metasoft program) needs to be set up before testing begins to directly connect the mobile transmitter with the receiver, also calibrating the $O_2$ and $CO_2$ sensors and the ambient air (pressure and temperature). The device is then ready to begin recording measurements and within a few seconds it is possible to verify the first values. The program provides a table row for each exhalation and the column can be adjusted individually. It is also possible to directly obtain in addition to the actual measured values, various calculated figures such as the RQ of $\dot{V}O_2$ and $VCO_2$ as well as the VE from respiratory rate and volume depth.

**5.1.4 Aerodynamics Testing**

Researchers from the Sports Medicine department of the Georg August University, Göttingen, proposed to improve the evaluation process of Paralympic Alpine Skiing athletes. The assessment for this study involved an investigation of air loads on the human body with the purpose of determining the drag force and drag coefficient of the *DPS* athletes (Brownlie *et al.*, 2010). The aerodynamics testing was conducted using the large low-speed, subsonic and atmospheric wind tunnel at the Technical University of Hamburg-Harburg. Drag refers to the component of aerodynamic force which acts on a solid object in the direction of the relative flow velocity or wind. Tests were performed to investigate the relationship between the posture and velocity of the skiers, who were of varying sizes and adopted a range of different torso posture angles, whilst in sitting or standing positions. The objective of this experiment was to correlate the basic drag data provided by the wind tunnel experiment with the posture performance for each skier as part of the overall evaluation process of the *DPS* athletes. The data obtained should have use as a means of predicting the impact of skier body position on their performance during alpine skiing events.

**Relationship between Wind Velocity and Drag Force**

This study, which was inspired by a previous experiment from the 1970's (Bendig, 1975), looks at drag and lift areas as applied to the human body (Schmitt, 1964) and these should, in theory, remain constant for all velocities provided that the posture of a person is precisely reproduced (Watanabe, 1977). Equation 1 demonstrates that a quadratic relationship exists between drag force and relative velocity, if air density and drag area are constant. It is quite difficult to select an ideal reference area for the human body since the body varies significantly in size and proportions (Hoerner, 1965). In this experiment, drag coefficient (equation 2) refers to the use of the non-dimensional dynamic pressure and a fixed reference area, an approach that is in line with former DLR practice (DFVLR). In the 1st campaign this fixed reference area was set at 0.5m², but for the 2nd campaign this reference area was changed to 1m².

$$\boxed{\mathbf{D = \tfrac{1}{2}\rho \,.\, A_D \,.\, V^2}} \qquad (1)$$

Where: **D –** Drag; **ρ** – Density; $\mathbf{A_D}$ **-** Drag area; **V-** Relative Velocity

$$\boxed{\mathbf{C_D = D/q\ S = D/0.5\ \rho\ V^2\ S}} \qquad (2)$$

Where: $\mathbf{C_D}$ **-** Drag coefficient**; D/q –** Drag Area**; S** – Area; **D –** Drag; **ρ** – Density; **V-** Relative Velocity

In terms of drag, the so-called **Drag Area** is useful for those cases where an area of reference is not obvious, or where several component parts are combined in some way (Hoerner, 1965), such as in the case of a skier. It was decided to also calculate the **Drag Area** (equation 3) in this study because the drag force is predominantly a function of the projected frontal area of the skier.

$$\boxed{\mathbf{D/q = C_D \,.\, S}} \qquad (3)$$

Where: **D/q –** Drag Area; $\mathbf{C_D}$ **-** Drag coefficient; **S** – Area

**Effect of Trunk Position upon Drag**

The best performances in Alpine Ski competitions come as a result of many factors (equipment, technique, and especially velocity). There are also other individual factors that make a significant difference between one athlete and another, for example, body mass, drag area, mass and quality of equipment, physiological training conditions, psychological training conditions, and technique and posture. The latter two variables are the focus of this study.

It is difficult for alpine skiers to maintain the ideal posture due to the natural characteristics of the terrain over which they will ski and compete. An investigation of the relationship between the posture and velocity of a skier could lead to an improvement in the performance of the athlete (Watanabe, 1978). From a mechanical standpoint, there are only three major forces acting on a skier travelling down a slope and these are: gravity; friction between the ski and the snow; air resistance of the moving body (Barelle, 2004). While gravity causes downward acceleration and consequently acts as a speed-increasing factor, the other two oppose motion and act as speed-reducing factors. Therefore, it is through changing both air resistance and frictional forces that postural changes may influence velocity. However, the role of these factors in Paralympic Alpine Skiing has not yet been investigated experimentally. The immediate concern is with the air resistance presented by the skier as posture changes can have more of a marked and varied influence on this factor than on frictional forces. The present study was designed to measure the actual value of air resistance presented by the alpine skiers in a wind tunnel, and to study its relationship with posture.

For the purposes of this experiment we were interested in some specific postures of the Paralympic alpine skiers, such as the manner in which they held their upper body (head, trunk and limbs). This was especially for the sit skiers, because the upper body represents the biggest movable area that the athlete can change. The head can be considered almost as a “rudder” because it leads the movement of the body. Although, in terms of dimension, the head is a small part of the body in comparison to the trunk, legs and arms, the head is relatively heavy and to keep it held in a good position requires the athletes to develop the specific musculature needed to maintain good trunk posture. The arms are also an important area to be considered as they are involved in the control of balance and the directional path. There is less that can be done to improve the drag area related to the legs of the sit-skiers as the legs are held firmly and securely within a protective shell.

Another interesting aspect associated with trunk posture is the fact that the ability to maintain the correct posture (in terms of quality and duration of movement) and to keep the body balance for each phase of the discipline being performed is very dependent on the level of spinal cord injury. For this reason the tests carried out in the wind tunnel proved interesting as an observation could be made of the coordinative reaction of each of the skiers when exposed to the air flow and to the subsequent changes in air flow speed, and their ability to maintain stable positions.

**General feedback applied to Field/ Competition Conditions**

In the artificial environment found in the wind tunnel, it is only necessary for the alpine skiers to concentrate on themselves and their body posture. However, during real training or competition situations their attention would be divided by a number of factors related to the environment itself and potential dangers, keeping to the set course of the race, speed control, coordination of arms movements, balance, posture and breathing.

As previously suggested in the 1970’s (Watanabe, 1977), although on that occasion related to a non-disabled alpine skier, it is the ability of the skier to ski with arms maintained tightly against the body trunk that determines their performance. If we look at the drag force generated as a function of air resistance on a runner, it can be said that this does not represent a significant percentage difference to the performance. However, if we look at the drag force generated as a function of air resistance on an alpine skier, although the relative wind speed measured could be the same, the drag generated by the body area may represent a significant difference to the outcome. Therefore, it is evident that in this specific sport of Alpine Skiing, any small modifications in posture can significantly influence the speed, distance and time travelled by the skier, and as a consequence the performance of the athlete.

## 5.2 Exercise Physiology Laboratories

### 5.2.1 Test Facilities

The Institute for Sports Sciences at the University of Göttingen has two different laboratories where evaluations took place. The first is equipped with a high performance treadmill-ergometer and the second with an electric bicycle ergometer. Both laboratories provide excellent facilities for the purpose of cardiopulmonary testing and analysis involving oxygen uptake for disabled people.

The first laboratory is a room (dimension 5.30m x 6.50m x 2.50m height) with natural lighting provided from windows at the top and has a radiator heating system. Entry is gained via a main entrance door to the laboratory and in addition there is an emergency door allowing a quick exit from the building and a speedier access to medical services, if necessary. Other features of the room include: a main power control panel complete with emergency shut off key for immediate interruption of the testing procedure; a wash basin for cleansing, mirror, waste bin; a small mobile table and a desk area for the computer operator; a desktop computer and telephone.

Fig. 11(a,b): View from the emergency exit of the Laboratory showing tripod and electrocardiograph; View from right side of the Laboratory showing treadmill and safety harness, power unit, desktop computer and interface.


Fig. 12 (a, b): View showing the wash area with basin for cleansing, mirror and waste bin, and pulley system; View from left side of the Laboratory.

The second exercise physiology laboratory is oversized for the cycle ergometer, however, it can be considered a multifunctional area as it has other test and evaluation equipment that can be arranged in the same space. It consists of three interconnected rooms, each of which can be isolated if necessary. For the purposes of this research, the bicycle ergometer was positioned in the centre of the main laboratory area. One wall of this room is of glass construction, allowing in plentiful natural light and providing a contemplative setting for the volunteers performing the test. This space also has radiator heating, opening windows to a second attached room allowing for ventilation, a wash basin, waste bin, and cabinets to store emergency equipment.

Fig. 13 (a, b, c): Centre section of the laboratory with the cycle ergometer; Head-on view of the laboratory; View from the right side of the lab.

### 5.2.2 Test Equipment

**Treadmill-Ergometer**

The principal piece of equipment provided in the first laboratory is the treadmill-ergometer (SATURN 300-125R hp cosmos sports & medical *GmbH*, *Nussdorf-Traunstein*, Germany). The device is located in a central position of the room and is set at ground level, therefore having the advantage of being very accessible for the tests conducted with the wheelchair athletes. The treadmill is mounted in such a way that the operating systems (mechanical and hydraulic) are located below floor level. The visible part of the treadmill consists of an embedded structure that also reinforces the surrounding framework, responsible for giving support to the subject under evaluation and ensuring their safety. The frame surrounding the treadmill/test site is 4.0m in length by 2.10m wide, with the area of the treadmill itself being 3.20m long by 1.25m wide.

Fig. 14 (a, b): Treadmill from rear and front perspectives.

**Pulley System**

The pulley system is a device external to the treadmill that must be connected to the wheel chair via a rope, making it possible to measure forces from 10W to 300W (Niklas, 1980/1987/1988/1989/1994/1997). A rail is fixed to the wall behind the wheelchair and the pulleys are mounted on this rail in two different axes. The rope that is attached to the wheelchair is guided by two pulleys. The load at the rope end can be increased (i.e. 20W each 3 minutes) during the course of the exercise.

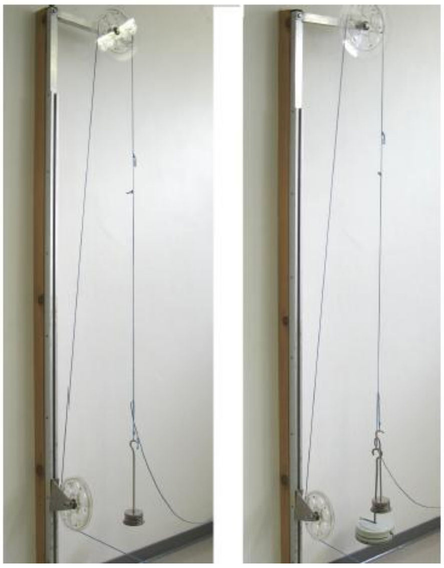


Fig. 15: Pulley System, auxiliary force admission.

**Electric Bicycle-Ergometer**

One of the pieces of equipment available in the second laboratory and used for this study is the electric bicycle ergometer (Ergoselect 200, *Ergoline GmbH, Bitz*, Germany). The brake system for the cycle is a microprocessor controlled eddy current brake with torque measurement: speed independent according to DIN VDE 0750-0238. The seat height is fully adjustable to suit the person under evaluation, ensuring a comfortable position for the task, and the graphic display unit is turned toward the person supervising the test. More characteristics of the equipment are detailed in Table 3.

**Table 3: Characteristics of the Ergoselect 200 Electric Bicycle Ergometer (Annex 4).**

| |
|---|
| Load range: 20-999 Watts, speed independent |
| Speed range: 30 - 130 n/min$^{-1}$ |
| Workload accuracy: max. +/- 3% between 100 and 999 W<br>max. +/- 3 W between 20 and 100 W |
| Load grades: 5 W or multiple over program |
| **Physical Specifications:** |
| Weight – approximately 68 kg |
| Max. Patient Weight – 150 kg |
| Display –115 x 88 mm or 320 x 240 Pixel |

Fig. 16 (a, b): Ergoselect 200 electric bicycle ergometer; bicycle graphic display unit.

### 5.2.3 Measurement Equipment

**Spirometer**

As can be seen in Figure 18b, the spirometer used in this study is the Metamax 3B (Cortex, 2000), which is a robust and portable cardiopulmonary exercise testing device for outdoor and indoor application assessment, weighing just 650 grams complete with batteries. It measures breath-by-breath the oxygen and carbon dioxide content of the air inspired and expired, as well as heart rate, temperature and air pressure under both laboratory and field conditions. The device is formed of two modules. The central computer unit used runs at 20 MHz with a 16-bit processor. The flow meter employed is the Ultra model (Triple-V turbine from 0.05 to 20 l/s) and has a resolution of 7 ml and an accuracy of 2%. The type of oxygen analyzer used is an electrochemical cell with a measuring range of 0-35%, an accuracy of 0.1% and a 90% strength mixing of the gas mixture of 100ms. The carbon dioxide analyzer works with infrared absorption and has a specified range of 0-13%. The temperature sensor is an NTC thermistor and has a measuring range of -55ºC to 155ºC with an accuracy of 1ºC.

**Table 4: Main Characteristics of the Spirometer Metamax 3B (complete table by Annex 5)**

| **Sensors:** | | **Physical Specifications:** |
|---|---|---|
| Flow/ Volume | Type – Turbine digital | Dimension (LxWxH) – 2x(120 x 110 x 45 mm) |
| | Range – 0.05 – 20L/s | Weight – 570 g (without battery) |
| | Resolution – 7 mL | **Electrical Specifications:** |
| | Accuracy – 2% | PC Interface – Serial (RS232) |
| $O_2$ | Type – Electro-Chemical Cell | Power Supply – Battery, Internal 7.2 V nominal; 2200 mA |
| | Range – 0 – 60 Vol. % | **Operating Conditions:** |
| | 0 – 100 Vol. % (optional) | Warm-up Time – approx. 30 min. |
| | $T_{90}$ Time <100ms | Temperature - 10º to max. +40 º C |
| | Accuracy – +- 0.1 Vol. % | Ambient Pressure – 500 – 1050 mbar |
| $CO_2$ | Type – ND Infrared | Relative Humidity – 0 – 99 % (non-condensing) |
| | Range – 0 – 13 Vol. % | **Minimal Computer Requirements:** |
| | $T_{90}$ Time <100ms | Processor – min. 2000MHz |
| | Accuracy – +- 0.1 Vol. % | Hard Disc Drive – >40 GB |
| Heart Rate | Polar® HR Set | RAM – min. 512 MB |
| | 3 Channel ECG (optional) | Disc Drive – CD-ROM |
| | 12 Channel ECG (optional) | Operating System – MS-Windows XP (SP2), MS-Windows Vista (32 Bit) |
| **Telemetry:** | | |
| Type – Bidirectional 19200 Baud | | Monitor – 17” TFT, min. 1024 x 768 Pixel |
| Frequency – 433 – 424 MHz | | Interfaces – LAN, min. 2 x USB, serial (COM) |
| Range – 1000 m | | Optional – Sound Card, CD/ DVD Writter |
| Interface – RS232 | | |

The silicone type pressure sensor works at a range of 200 mbar to 1050 mbar with an accuracy of 1.8%. The heart rate monitor is a Polar diameter determined by default. The Metamax 3B can be used for a variety of functions as detailed below:

- Smoothing of the values (pointwise breath-based or time-related) by a moving average.
- Calculation of the anaerobic threshold by V-slope method and minimum method (based on $O_2$ and $CO_2$ equivalent).
- Calculation of the oxygen debt and the maximum oxygen uptake.
- Print a report as a 9-box graphics for Wassermann, as ergometry/ calorimetry standard report or custom.

The laboratory has a computerized system of control along with computing hardware support and data-processing software aimed at maximising the use of the equipment and facility. The Metamax 3B is preloaded with its own specific Metasoft CPX software, which is modular and incorporates a database to include subject data, a measurement module and an evaluation and calibration module. After the measurements take place, the values are considered and processed using the evaluation mode. More characteristics for this equipment are detailed in Table 4.

**Equipment used during Spiroergometry**

The wheelchair dependent athletes used their personal wheelchairs whilst taking part on the treadmill and the stand-ski athletes were seated on the bicycle. All athletes were dressed appropriately for the test. The heart rate monitor used was the Polar® HR set (Polar Electro Oy HQ, Kempele, Finland) and was adjusted to each of the athletes. In addition, the wheelchair athletes were fitted with a shoulder harness which was attached to the framework surrounding the treadmill in order to reduce the risk of accident.

Fig. 17: Portable Electrocardiograph.

The cardiopulmonary exercise testing equipment used was a Metamax 3B (*Cortex Biophysik GmbH*, *Leipzig*, Germany) spirometer, a portable 3-channel electrocardiograph model AT-4 EKG (*Schiller AG*, Switzerland, fig. 17), and a SCOUT (*SensLab GmbH*, *Leipzig*, Germany) lactate analyser. Two computers were also used during the experiments with a desktop computer and interface controlling the treadmill, and a laptop computer for monitoring the spiroergometry. Both computers were equipped with specific software for their individual tasks.


Fig. 18 (a, b): View from right side of the Laboratory, including desktop computer, interface and lap top; Spirometer (Metamax 3B).

### 5.3 Wind Tunnel

#### 5.3.1 Test Facilities

The Technical University of Hamburg-Harburg operates a large low-speed wind tunnel and provides an excellent facility for the aerodynamic analysis of sports performance at low to moderate speeds, as proposed by this study.

**Table 5: Test Facilities**

| *Dimensions* | |
|---|---|
| Gross Length: 83.2m (over 2 subsurface floors) | Length: 42.0 m (maximum dimension) |
| Height: 10.5 m | Width: 5.5 m |

#### Operating Mode

The tunnel is operated in a closed circuit loop, called the "Göttingen" mode.

**Outline of the Wind-Tunnel Configuration**

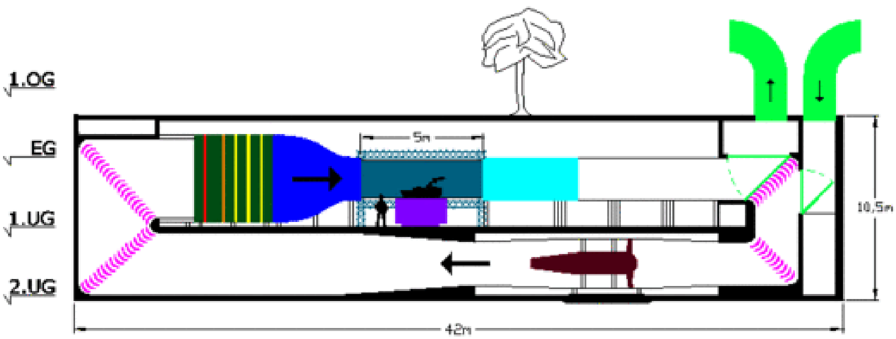



Fig. 19: Schematic View of the Wind Tunnel (http://www.tu-harburg.de).

#### Test Section

The test section is 5.5m in length and features a central turntable capable of rotating 360° and this is connected to a 6-component balance. The open test section features manual and optical access from the top and the two lateral sides.

**Table 6: Test Section of the Test Facility**

| *Test section, cross section and corresponding maximum velocity* |
|---|
| Length of test section: 5.0 m |
| 2.0 m x 3.0 m: approx. 30 m/s |

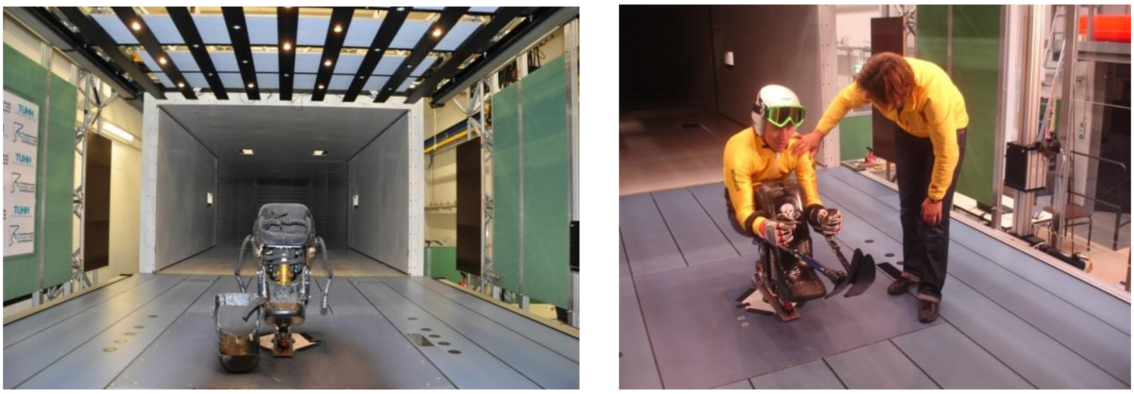


Fig. 20 (a, b): Frontal view from the test section; Seated mono-ski fixed to the balance.

Fig. 21: Wooden plate adapted to skis and fixed to the 6 component balance.

### 5.3.2 Test Equipment

**Sports Equipment for the Athletes**

All skiers used their normal racing equipment and clothing during each test session, consisting of: helmet, goggles, gloves, back protector, boots, ski suit, underclothing, and ski poles. All the skis, both mono and double, were perforated so they could be statically fixed to the platform. No anchor points for the ski pole tips were provided meaning that athletes were unable to set them down during each period of evaluation.

### 5.3.3 Measurement Devices and Data Acquisition

The wind tunnel situated at the TUHH has a computerized control system equipped with modern ‘state-of-the-art’ data-processing software and computer hardware, all of which serve to maximise the use of the facility and equipment. A number of measurement devices are provided to facilitate the acquisition of computational fluid dynamics quantities.

**Six-Component (External) Balance**

The wind tunnel features an external subfloor integrated 6-component balance (SCHENCK Process *GmbH*, *Darmstadt*, Germany) that can measure forces of 200N to 400N and moments up to 200Nm. The balance is connected to a flush-mounted turntable which can be moved to allow for rotation and which supports operation in two different kinematic configurations (adjusting to different load levels).

**Table 7: Test Facility Measuring Equipment**

| ***Measuring equipment*** |
|---|
| 6 component balance: non-decoupled weighing platform (under floor) |
| max. model weight: 150 to 250 kg |
| max. forces: 200 to 400 N |
| max. moments: 200 Nm |

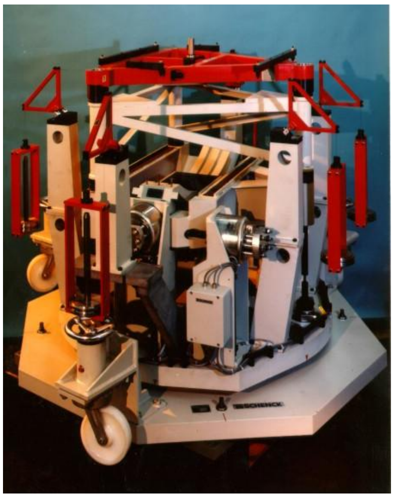


Fig. 22: Six-component (External) Balance (http://www.tu-harburg.de).

**Speed Indicator**

The instruments used for the measurement of wind speeds come from environmental and industrial measurement instruments (VAISALA Group – Vantaa, Finland).

- Velocity measurements non-intrusive turbulence-resolving LDA
- Velocity measurements using hot-wire probes

#### 5.3.3.3 Barometer

The atmospheric pressure is measured in the settling chamber, the section that precedes the test area. Additionally this pressure is also used to determine the wind velocity through the plenum method.

- pressure by means of static/dynamic pressure probes

#### 5.3.3.4 Thermometer

In addition to pressure, temperature and humidity are also measured in the settling chamber. The air density is calculated according to these parameters.

#### 5.3.3.5 Photographic Cameras

The photographic equipment used for taking the lateral images was a Canon camera (model EOS 350D, Canon Zoom Lens EF-S 17-85mm 1:4-5.6 IS USM 67mm). Two different cameras were used over the two separate campaigns to record images from the frontal plane. These were a Nikon camera (model D5000, Nikkor 18-105mm VR 1:3.5-5.6 IS USM 67mm) for the first, and a Nikon (model D90 - Nikkor AF-S 18-200mm VR 1:3.5 - 5.6 G2 ED) for the second campaign.

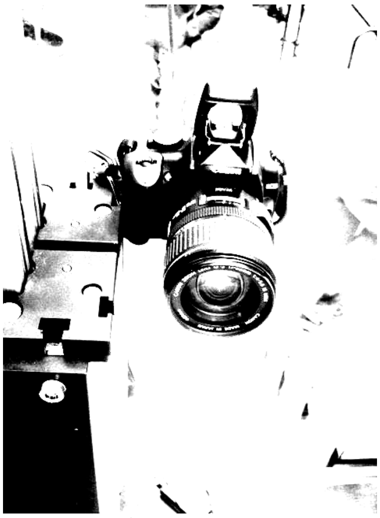
 

Fig. 23 (a, b): Camera used for lateral shots (Canon); Frontal shots taken using 2 different cameras (Nikon).

## 6. Equipment, Sport Medicine and Sports Achievements to the Science of Handicapped Sport

### 6.1 Wheelchair (WC)

#### 6.1.1 Historical Development of Manual Wheelchairs

A very simple object was invented in China in the 3rd century that consisted of only one wheel up front and two fixed supports at the back. It was used to transport sick people, or people with some form of physical deficiency to a place called the Fountain of Youth, where according to Chinese folklore the disease could be cured. In this context, the triangular link is evident between deficiency (movement restriction), transportation (the need to develop a supportive technique for ambulation), and the aquatic environment as a rehabilitative element. According to Carriel (2007), the first historical evidence of the existence and use of a WC can be found in an inscription engraved in stone on a Chinese sarcophagus (Fig.24, Annex 6) dating from the year 525AD, although some studies from German Johan Haustach consider the invention of the WC only in the 17th century (Sawatzki, 1999).

The development between the 16th and 17th centuries of assistance with mobility aimed at people with a walking impairment was limited to the adaptation of some objects with wheels. Only in Germany during this period did the WC really come into context through an object developed by Stephen Farfler (Fig.25, Annex 6) that was made from wood and propelled manually. This invention, although made by hand, allowed him to be the first man to use a WC as a means of rehabilitation and giving accessibility and reintegration into society.

The first real WC was built at the end of the 18th century and was very similar to the modern design (Fig.26, Annex 6). The need for good mobility was first contemplated based on a self-propulsion system that had big wheels to the front and free moving casters at the back. Other important aspects were introduced later on to improve comfort.

At the end of the 18th and beginning of the 19th centuries, a WC developed by John Dawson (Fig.27, Annex 6), had a triangular design with a rotatable wheel to the front and a steering wheel that allowed the user to guide the movement of the chair. The upper classes of society were very interested in this new device and particularly in the type of transportation that it enabled and the high status associated with the new innovation, rather than its rehabilitative function. The Dawson project inspired the creation of a very efficient and well known contemporary means of transportation, the bicycle (Fig.28, Annex 6).

However, it is believed that other ways of locomotion for disabled people were developed in the 19th century (Fig.29, Annex 6). They had high seat backs for support and rims on the front wheels that facilitated manoeuvring and propulsion. In the middle of the 19th century, the Civil War in the United States of America (USA) established the first milestone in the history of the North American WC with the first patented WC in the USA in 1894. It was a simple wooden chair with a rigid seat and big wheels at the front (Fig.30, Annex 6).

New materials have continued to be tested and used in the structure of the WC with the aim of improving its usability and functionality (Fig.31, Annex 6). The mechanical aspects of the equipment are designed with the objective of making it light, something that will always help the needs of the individual. However, in the USA in the 1930's, the development of the wheelchair presented very rustic and basic features, even for that time. The model of the WC was heavy with a structure made of steel tubes, a very rigid seat and with no adjustable features, which proved to be very inefficient (Fig.32, Annex 6). In 1936, an American company made improvements to the wheelchairs and obtained the first patent for a collapsible WC in an “X” shape built from steel tubes (Fig.33, Annex 6). In the 10 years that followed the concept was introduced of WCs with removable parts aimed at facilitating their transportation and maintenance.

**Sport Wheelchair and Other Variants**

From 1948 when the Stoke Mandeville Games were held for the first time, the idea of using the wheelchair for taking part in different types of sports began to be considered. However, there was still the need to construct a device that would be functional enough to allow greater mobility whilst also being light, resistant, safe and versatile enough to enable good performances from athletes.

New alternatives were developed in the 1980s, emphasising its use in different sports (Fig.34, 35, 36, Annex 6), as well as for rehabilitation in hospitals, such as the orthostatic wheelchairs used at the Sarah Kubitschek Hospital network in Brasília, Brazil (Fig.37, Annex 6), or the “Sit-Up/ Stand-Up Wheelchair” model developed in Germany with the same objective (Fig.38, Annex 6). With the advent of Industrial Design, other WC products for the elderly were developed in which the main innovations were the segmented seats (Fig.39, Annex 6) and frontal traction (Fig.40, Annex 6). The concepts behind these projects were aimed at a better integration of people with special needs into their daily activities, and not just the aesthetics or cost of the product itself. According to Krizack (2000), aspects related to costs and social benefits should be considered, evaluated and also adapted for other wheelchair projects.

In the last three decades, social factors such as accessibility and social inclusion have driven the development of these products with there being more social responsibility, such as WCs where aspects related to aesthetics, ergonomics, comfort, safety and efficiency are seen as a secondary gain, whilst the primary aim is the use of alternative low cost materials. Although these projects don't contemplate physical or physiological rehabilitation, which can be considered a potential health risk over time, they have in terms of cognitive, psychological and social aspects obtained relative success and given greater access to the lower classes, as can be seen from the prototype developed by the British doctor Huckstep who developed a WC to assist the victims of landmines in Uganda. Other good examples that should be mentioned are the “Free Wheelchairs Mission” that adapted WC's of PVC into metallic structures to be used in the poorer areas of Somalia; the “Mekong” model developed by an english social foundation called Motivation that developed a versatile product used for people with special needs in many places in the world (Fig.41, 42, 43, Annex 6).

**Hi-Tec Wheelchair development**

In the past, researchers were seeking solutions to help people with disability move around and this was the moment that the WC was created. The need for further development of the WC keeps motivating engineers, project designers and technicians to make improvements to existing designs and to develop new products and adaptations that will have a big impact. The Yamaha Motor Company, for example, developed the 2000 model that uses an electric motor, but can also be propelled manually (Fig.44, Annex 6). Other electric WC models allow users with more severe disabilities to move without the need for propulsion that involves any active participation from the user themselves, thus facilitating comfort, safety and pleasure (Fig.45, Annex 6).

**The Wheelchair and Social Attitudes**

It is believed that the historical importance of the development of the WC is related not only to technological and rehabilitative aspects, but also to social aspects. It is important to consider the development of WCs from the 16$^{th}$ century to date, in order to better understand the characteristics and tendencies that this device has had over its history.

Historical facts directly influenced the development and transformations undergone by the WC over the years, changing its use in 2 areas: rehabilitation and transportation for privileged society. Nowadays, its health applications in hospitals plays an important role in the rehabilitation of people with walking deficiencies, giving more mobility to these people with special needs and amplifying the number of activities in which they can participate, such as to practice some sports, and with this the quality of their lives are improved.

**Mechanical Aspects of the Wheelchair to be considered**

Statistics sources (IBGE[2], Statistisches Bundesamt[3], UN[4]) in the last decade have presented an increase in the world population that have any type of physical or mental impairment and that require the use of WCs. This reinforces the demand for research in this area to be conducted in order to improve the knowledge related to it, and this will reflect in the way the needs of these people are met, ultimately improving the health and the daily activities of these individuals.

[2] Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*).
[3] German Federal Statistics office.
[4] Union Nation Organization.

In Brazil, studies related to aspects of the integration between physical/functional training and ergonomics, or the product development area for rehabilitation of people with special needs, has been insufficient in relation to the number of people, irrespective of gender, age or the physical deficiency that requires them to need a WC or rehabilitation procedure. This has motivated new researches in the areas of movement science and rehabilitation.

From the moment an individual suffers a physical deficiency that leads to the use of a WC, this motor dysfunction is associated with a series of physical, physiological, cognitive, and frequently psychological changes that require a vast process of adaptation and relearning of motor and behavioural skills.

Anthropometric studies (Jarosz, 1996) and functional evaluations are needed to adapt devices for people with special needs, as the required parameters for their development are often found in a population without motor disabilities. Dimensional differences are present for various reasons, as the physical impairment of an individual affects the functional and anatomical development of the motor system. In the design of new equipment, angular and dimensional variations, distinct body postures and functions to be performed by the user must be taken into account (Ramos *et al.*, 2003).

The developmental characteristics of a WC should be based on the needs of each individual or group of people that belong to a specific anthropometric group, and on a functional evaluation of the users, the equipment and the interaction between man and machine. Van der Woude *et al.* (1989/2001) emphasized human factors, evaluation of physical capacity and effort required as being the fundamentals for the ergonomic and functional development of a WC in order for it to satisfy the physical and psychological needs of the users. The force generated by the user of a WC, the equipment itself, and the interaction of both are vital for good performance and the efficiency of its usability in the context of man/machine.

Reports presented by WC users are fundamental for its development in relation to functionality, safety, efficiency and comfort, especially in the moments of propulsion and getting in and out of the device. If these factors are not considered during the development of the WC then the process of rehabilitation for each individual can be compromised, breaking the fundamental basics of the development of assistive technology for giving better accessibility and quality of life to those affected by any type of impairment (Bersch, 2005).

The need for a multidisciplinary approach is another very important factor for the development and use of a WC. The confidence given by the synergy between the clinical, exercise and ergonomic (Engineering) areas allows the WC dependent person to have a greater understanding of their functional capacity, better equipment utilization, a shorter adaptation time, an improved performance, increased cognitive ability, greater acceptance of the use of the WC and increased personal satisfaction. It should be emphasized that the complexity of a rehabilitation program for paraplegic patients is directly related to the degree of motor and psychological restrictions that these individuals have, mainly at the beginning of their treatment.

It is important to note that the development of methods and materials centred on these users should mainly follow principles of specificity, individuality and suitability. It should aim above all at a high level of functionality and safety, and if possible, at a better level of performance and comfort that will allow the users to naturally perform their physical activities without risk to their health, thus positively influencing their daily activities and improving their quality of life.

**Wheelchair Spiroergometry and Physiological Aspects**

Spiroergometry evaluations of athletes with special needs have advanced in different types of summer and winter Paralympic games. Theoretical discussions related to the use of dynamic exercise in wheelchairs in order to diagnose the sports performance of athletes took place in the 1980's in some of the first research studies on this topic (Niklas, 1980), with this being the same period when alpine skiing for WC dependent people was included in organised competitions. The occurrence of performance evaluations of people with a deficiency in competitive swimming, as compared to those without a deficiency, was also done in this period and gave the possibility of verifying the relationship between mechanical and physiological work. (Niklas, 1987/1998). A more in depth physiological evaluation of spinal lesion athletes in WC races has been carried out in order to obtain the best parameters for the performance and safety of WC users in this type of sport (Bhambhani, 2002).

Spiroergometry testing on an ergometric treadmill (ET) for WC dependent people has been used with the aim of verifying the related parameters for the fitness of the individual (Niklas, 1987/1994; Veeger, 1991). The maximum workload performed by the person being evaluated, heart rate (HR), lactate concentrations and the peak of oxygen uptake ($\dot{V}O_{2peak}$) are all collected during the test. Different ET protocols for WC athletes can be used for this evaluation. The choice of protocol will depend on the level of the lesion and the type of sport that is being performed. A specific ET protocol for WC users was used for this research, based on studies performed over the last three decades involving different types of athletes, such as swimmers, divers and WC athletes (Niklas, 1988/1989/1998; Bhambhani, 2002).

Other variations have been developed for performing tests on an ET with WC athletes. Researchers from Loughborough University, UK, use a rail system parallel to the ET which is fixed to the WC. This allows the WC to remain stable on top of the treadmill, helping the person being evaluated to concentrate more on their physical activity in an attempt to guarantee the best performance. The Exercise Research Centre at Leipzig University, Germany, uses a Race WC that adopts a similar system to the one used at Loughborough University but also has an inclined ramp that can be used during the tests. However, researchers from Göttingen University, Germany, use neither of the previously described systems, with the WC sitting freely on top of the ET and adjusting a safety belt around the person being evaluated, adapting it to the ET structure in case there is a loss of WC control during the test. The type of system that was adopted for this study is justified because the person being evaluated must present a maximum cardiorespiratory performance and coordination control of the WC whilst on top of the ET. In fact, there is some discrepancy in the protocol and method used (Lakomy, 1987).

The tests can be classified in three basic ways as shown in Table 8, and one should be chosen according to what suits best the case being evaluated. The ramp protocol is used by some researchers, but one cannot rule out the use of evaluations that provides a steady state or equilibrium load over a specific period of time, relevant to checking the aerobic fitness of the evaluated individual.

**Table 8: Types of Ergometric Tests.**

| | **Tests** | |
|---|---|---|
| **Type of work** | Continuous | Non continuous |
| **Load applied** | Single load (not used any more) | Multiple load (2-3 min) |
| **Exercise intensity** | Submaximal test – when test end is below 85% $HR_{max}$ (is not used due to a less diagnostic sensibility) | Maximum – When test ends at the $HR_{max}$ |

In Sports Medicine, according to Pansold (1983), maximum ergometric tests are classified in specific tests, semi-specific tests and non-specific tests for each type of sport. In order to have a maximum ergonomic test with a high level of specificity, it is important that the evaluation presents a close relationship with the performance structure desired. (Schnabel, Harre & Krug, 2008).

The semi-specific evaluations performed on the ET, as is the case for this study in which paralympic alpine skiers are evaluated using their WCs, allows the determination of parameters such as mechanical and physiological performance measured in Watts (W), the relationship between two variables called efficiency (measured in percentage points), absolute and relative oxygen consumption (mL/min), lactate production (mmol/L) and vital signs.

Testing on an ergometric treadmill with a WC was chosen, using a progressive load increase to determine the oxygen consumption of the athletes in question, according to a method used by the Evaluation Centre of the Sports Science School at Göttingen University. This method involves the person being evaluated performing a specific movement to generate propulsion of the WC, as well as maintaining a body posture that is more in accordance with that held in the sit-ski sport, which are situations not found when using the arm crank ergometer.

The Spiroergometry Test Equipment must be calibrated at least 30 minutes before testing and it is necessary to warm up the system by activating it before measurements can be taken. Previous calibrations are needed as some physiological variables, such as expired minute volume, are analysed in the presence of water vapour, a condition called BTPS (body temperature pressure saturated). Upon testing, electrodes for the electrocardiography, HR frequency and spirometry are place on the person being evaluated by the members of the research staff that manages the evaluation process.

The performance in this test depends on the endurance strength and coordinative ability of the individual. Many factors, such as the type of exercise, level of training, gender and age, influence the maximum oxygen uptake score. In general it is believed that variations in the $\dot{V}O_{2max}$ during the performance of different types of exercise reflect the quantity of muscle mass used (Blomquist *et al.* 1982, Lewis *et al.* 1983). However, it is important to emphasise that for this chosen evaluation, the cycle ergometer used was the ET for which the effort was made through use of the upper limbs.

According to studies by Magel and Faulkner (1967), and McArdle *et.al.* (1978) involving tests using the arm crank ergometer, the values of the aerobic capacity represent only 70% of the total performance of an individual on an ET.

In this study, an evaluation of the physical fitness of the athletes using a WC on an ET was chosen as the author believes that the evaluation is more concrete in relation to the performed movements and body postures kept during data collection, as well as the application and usability of the findings for WC dependents in comparison to other ways of performance. It is extremely important in AS competition to have knowledge of the cardiopulmonary functional capacity of the "pilot athlete", with the readiness to react and the reaction itself being essentials for a best performance with excellent control and low risk. Another interesting aspect associated to this evaluation is that dependent on the level of spinal lesion suffered, it becomes very difficult to maintain body posture (in terms of quality and duration of movement) and body balance during different moments of the AS competition, which justifies the need to understand the capacity and limitation of the athlete.

## 6.2 Alpine Skiing for Disabled People

The natural evolutionary consequence of a contemporary sport is the organisation of its whole structure (rules, categories, federations), culminating in different competitions. The development of new techniques and equipment made the participation of special needs athletes possible in Alpine Ski competitions (Slalom, Giant Slalom, Super Giant Slalom and Downhill). Nowadays, Alpine Skiing is divided into standing, sitting and visually impaired classes (Table 8), which keeps the same criteria used in Nordic Skiing (IPC).

**Table 9: Alpine Skiing basic functional classification, not complete (http://www.skiteam-alpin.de).**

| **Skiers** | **Functional Classification** | | **Description of the Functional Classification** |
|---|---|---|---|
| **Standing** | LW1 | | |
| | | LW2 | |
| | | LW3 | |
| | | LW3/1, /2 | |
| | | LW4 | |
| | | LW5/7 | |
| | | LW5/7-1 | |
| | | LW5/7-2 | Skiers with disabilities in both upper limbs but on two skis and without poles; or prostheses and/or orthotic allows for use, as with dysmelia, arm amputations |
| | | LW6/8 | |
| | | LW6/8-1 | |
| | | LW6/8-2 | Skier with disability of one upper limb; or paralysis of an arm; or Dysmelia/Amelia, running on two skis and with one pole, as with unilateral arm amputees |
| | LW9 | LW9/1, /2 | |
| **Sitting** | LW10 | | |
| | | LW10/1 | Athletes with disabilities of the lower limbs with no functional sitting balance |
| | | LW10/2 | Mono-skier (little trunk musculature) |
| | | LW11 | Disabilities of the lower limbs with a regular to good sitting balance |
| | LW12 | | |
| | | LW12/1 | Mono-skier (low incomplete Spinal Cord Injury) |
| | | LW12/2 | |
| **Visually Impaired** | B1 –B3 | B1<br>B2<br>B3 | |

### 6.2.1 Historical development of the Monoski

The development of Alpine Skiing began in the last century, as shown by Matthias Zdarsky in his book *"Alpine Lilienfelder Skifahr-Technik"* in 1896, in which he presents techniques and equipment from the beginning of the sport (Barth and Brühl, 2005). However, the development of AS and adapted skis for people with special needs are part of a more recent reality, beginning in the 1950's when amputee veterans of World War II began skiing as an experimental and leisure form. The West Germans are credited with the invention of skis attached to rods that were used to help maintain balance. At that time, during the Winter Games, there was the first participation of disabled people in organised competitions.

At the end of the 1950s and beginning of the 1960s, skiing for amputees was the mainstay of the handicapped sport. It was at the end of the 1960s and beginning of the 1970s that other people with differing forms of disability (e.g. poliomyelitis) began skiing, using the technique developed for the amputees (Pringle, 1987). It was also in this same period that this sport began to gain more attention when the amputees began experimenting with prosthetic skiing and the visually impaired started to participate in this kind of activity. In the late 1970s, the most important innovation was the development of a technique called "Four-Track", which allowed many people with severe deficiencies to ski. In the 1980s, a new technique was developed called "sit-skiing" (Pringle, 1987). This allowed the participation of people who were wheelchair bound to take part in this type of sport.

### 6.2.2 Monoski, Sit-skiing, and Other Variant Techniques

The initial definition of monoski is linked to the equipment used and the way that the individuals position themselves when skiing. Therefore, an amputee skier with only one leg and skiing on foot will be practicing monoski. However, a new meaning was given to this definition when the amputee was able to use a monoski in the seated position (Fig.46, Annex 7). In 1975, a patent was given for a piece of sports equipment called the "Snow Monoski". It is a monoski that can be used by anyone that is in the seated position and who can then control their speed, direction and braking. This equipment consists of a ski with curved side edges, which in turn supports an articulated structure that gives support for a seat. The Snow Monoski was developed without devices for the control of direction in order to decrease its weight and potential additional risks (Fabris, 1975). Another type of equipment was later developed called a "Ski for the handicapped" (Fig.47, Annex 7), that is made up of a cell similar to a kayak, mounted on top of one or two parallel skis, where the individual can sit and accommodate the legs (Olpp, 1986).

**Sit Skiing**

This technique has been used by people who are unable to ski in the standing position, such as those who have muscular dystrophy, multiple sclerosis, cerebral palsy, paraplegia and tetraplegia. It has been adopted since 1980. The way to change the direction of the device is through a lateral inclination of the body and by the contact of the ski and outriggers with the snow, on the same side as the desired direction (Fig.48, Annex 7). Another way of turning at an early phase of the learning process is through a guide positioned behind the learner, and who intervenes in a manoeuvre when needed. The sit-skiers have become very proficient in many different situations, without requiring the direct intervention of the instructor, which characterises an important aspect of the relationship between the sport and the positive effects it has on improving motor, psychological and motivational conditions. The use of the Sit-Ski/Monoski requires upper body strength, which makes it more difficult for people that have high paraplegia or those that are tetraplegic.

**Four Track Skiing**

This name is derived from the track that is left in the snow. It requires two skis and two outriggers and has been used for people that need assistance to move around or who have poor balance control. However, they can still ski in the standing position, even without having total motor control of the legs to ski without any kind of support.

**Three Track Skiing**

This technique requires one ski and two outriggers and its name comes again from the type of track that is left in the snow. It has been used by people in the standing position that do not have one of the legs or feet to ski. The sit-skiers also use this technique as they ski with a monoski and two outriggers.

**"One" Track Skiing**

Some experienced skiers that use the previous technique, have learnt to ski using ski-poles and do not require the outriggers, which in fact was the only possibility for people with just one leg to ski before the creation of the outriggers.

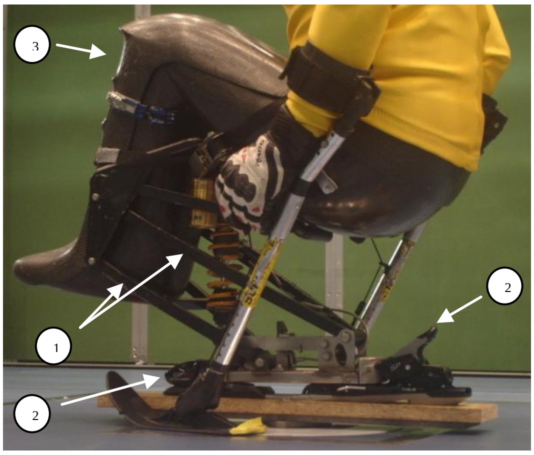
### 6.2.3 Bi-Skiing

Other possibilities for adaptation of the technique and equipment are available for people with special needs for the practice of alpine skiing. The Bi Ski is a piece of equipment with two long skis and because it is close to the ground, it does not require long outriggers (Fig.49, 50 Annex 7). It is an option that provides greater ease of use. Skiers with not much upper body strength and who have poor control of the trunk, such as those with high paraplegia or tetraplegia, can better adapt to this type of technique.

### 6.2.4 Recent Sit-ski Development

The most recent sit-ski model adapted from a monoski is made of carbon fibre and weighs approximately 13kg. Its use is more difficult for WC dependent people as it requires more muscle strength to manoeuvre than the other previously developed devices. However, individuals that use wheelchairs for their mobility and training, and are capable of developing the strength and equilibrium of the trunk and upper body muscles are more suited to using this equipment and its respective technique.

The frame is made of a resistant metal alloy and has a shock absorber system of adjustable springs placed below the sit-ski shell, which plays the same role as the legs of someone without motor deficiencies (Fig. 51). The height and width of the seat can be adapted to the dimensions of the user and the foot support has infinite adjustment possibilities. At the base of the sit-ski, the binding plate perfectly simulates a ski-boot which makes the equipment compatible with any make of ski. The sit-ski also provides thermal comfort. An external fairing covers the legs, protecting them from the wind and snow, whilst at the same time giving a better aerodynamic function for the entire sit-ski/skier. On the inside part there is also a coating used to improve the comfort of the person while seated.



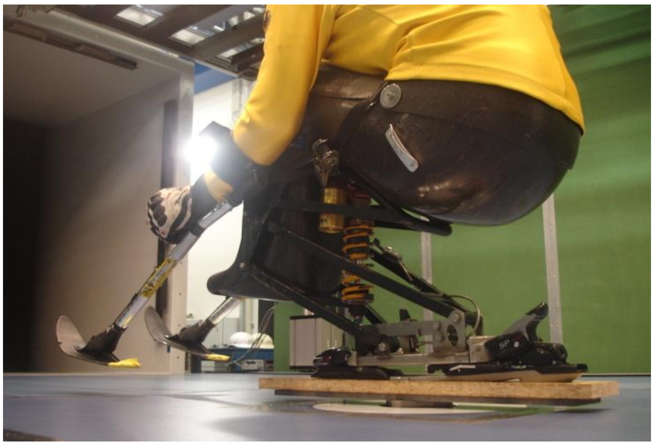



Figure 51: 1. Two parallel swings provide optimum shock absorption. Both pull and pressure are adjustable. 2. The binding plate perfectly simulates a ski boot, making it compatible with any make of binding. 3. Foot fairing and foot fairing cover for seat widths.

### 6.2.5 Mechanical Aspects of the Sit-ski to be considered

In its most primitive design, a sit-ski is composed of a frame attached over a ski (Fig.52, 53, 54, Annex 7). A seat is mounted on top of this frame in such a way that it has a rotational axis that is above and perpendicular to the plane of the ski, allowing the seat perform a trajectory arc above this axis. The shock absorbers have one end that is connected to the seat support, which is placed between the seat itself and the axis of rotation, and the other end is fixed to the base of the frame. Consequently, the movement of the seat causes compression or stretching of the shock absorber. The proportion of the seat movement in relation to the compression of the shock absorber is approximately 3.5:1 (La Come, 2000).

For the development of new equipment it is important to consider its evolutionary process and aims. From the 1980s new alternatives were being developed for sit-skiing with an emphasis on sports performance. The functionality and usability of new materials have been tested and used in the construction of the structure and mechanical function of the sit-ski, aimed at improving safety, performance, comfort, ergonomics, versatility and weight of the equipment, as well as the interaction between user and the equipment. The biggest advantage is that performance has improved and that the athletes can move progressively quicker. The disadvantage is that there has been an increase in the risk of more severe accidents.

The development of adapted equipment, even though more expensive, is prioritised for elite athletes that help researchers to develop technological innovations for more efficient products that can subsequently be produced on a large scale by industry for people with disability. This provides them with sports alternatives and better access to the same equipment and opportunities offered to elite athletes.

### 6.3 Handicapped Alpine Skiing and some Physiological Aspects

In academia, there already exists data related to the evaluation of cardiopulmonary performance in Paralympic Alpine Ski athletes that were collected *in loco* (Goll, 2012). However, the author of this study believes that characteristics of the equipment, sports modality and the environment where the evaluations were performed offer less comfort for the athletes than the environment of a laboratory, and additionally the evaluation equipment is more likely to suffer alterations in its performance during testing in such environments, which can interfere with the reliability of the data.

The evaluation group in sports medicine based at the University of Göttingen first had the opportunity in 1998 to evaluate the performance of some of the *DPS* athletes in a laboratory, simulating the effort required for this type of test as they do not have access to the environmental conditions required to perform this type of evaluation in the field. This process has enabled studies regarding performance structure and the determination of relevant performance parameters to take place for this type of sport.

Alpine Skiing for stand skiers, especially in tests that require changes in direction, is a type of sport characterised by high levels of isometric eccentric muscle contraction due to the maintenance of the squat position in opposition to the gravitational and centrifugal forces. To perform Handicapped Alpine Skiing at a high level requires a good degree of fitness from the athlete that has to be in synergy with the demand from this type of sport and to compensate for the possible imbalances created by disability. The athlete must develop muscle strength, power and anaerobic capacity, aerobic power, flexibility, reactivity, balance and coordination. When a Paralympic stand skier with an amputation below the elbow is considered, we can see that the deficiency especially brings partial biomechanics difficulties, although the physiological responses are the same as an Olympic athlete (Andersen & Montgomery, 1988). Tests simulating giant slalom races performed by Italian athletes belonging to the LW2 category (above knee amputated standing athletes who ski on one leg and stabilize their corporal centre of mass by holding outriggers) do not differ significantly from the metabolic standards measured in sit-skiers during the same tests (Bernardi & Schena, 2011), although for paralympic sit-skiers, physical, physiological and biomechanical adaptations are needed.

It is noticed that when the low levels of glycogen found in the biopsies of slow twitch muscle fibres of experienced able-bodied athletes are compared with those of non-experienced athletes, that the depletion of glycogen is greater. In this situation, it is assumed that the aerobic metabolism is essential for elite athletes. Based on these results we can see that not only the strength and anaerobic capacity/power, but also aerobic power plays a very important role in the performance of alpine skiing. Evaluations performed on sit and stand skiers from the last three Paralympic Games indicate that the achievement of a successful result in those events was related to $\dot{V}O_{2peak}$ (Bernardi & Schena, 2011).

At least two advantages of aerobic training (high $\dot{V}O_{2peak}$ and anaerobic threshold) for alpine skiers can be considered. The aerobic energy contribution during the race would be greater due to the faster way that the oxygen becomes available and is consumed, allowing a lesser dependency on the lactate anaerobic metabolism, which is especially useful for events where the outcome is dependent on two performances. It is the increase in recovery capacity due to high aerobic fitness that reduces the time after each exercise session, with this being very useful for each session by allowing a greater volume of training to be conducted.

The training of Alpine Ski athletes is quite comprehensive but should be more focused on strength work, maximum explosive power, and anaerobic and aerobic capacity/power to be successful. During the pre-season, training should aim to improve the energy systems (aerobic power and anaerobic capacity) through a high volume of endurance training. In the pre-competition period, the training should be concentrated on strength, maximum explosive power, anaerobic power, and using increased muscle coordination exercises during concentric and eccentric muscle activity. The Pilates technique that also uses eccentric exercise, among others, combines very well the type of training required and has been gradually adapted to improve the performance of Paralympic Alpine Skiers.

### 6.4 Sit-skier and Postural Aspects

For a better understanding of the characteristics and tendencies of this sports device over the last three decades, it is important to know a little of the history and evolution of this type of sport and its equipment, which nowadays are part of a complex technological development chain. Anthropometric, biomechanics (Fetz and Müller, 1991) and kinesiology studies are fundamental for the adaptation of victims of SCI to Alpine Skiing. It will help the comprehension of the possibilities related to manoeuvrability that can exist, based on the remaining movements that people with motor dysfunction present. Differences in dimensional, angular and postural conditions of athletes during the performance of Alpine sit-skiing exist and should be noted.

The role of the pilot/athlete who is submitted to testing in order to evaluate reactions is very important for the development of the athlete/sit-ski model in relation to its compatibility with the sport, safety, performance, efficiency and comfort. This has to be combined with the athlete's perception of their own performance, the performance of the equipment, experiences during the pre-season training period, and the knowledge transfer of acquired experiences related to the development of other assistive technology equipment (i.e. Wheelchair).

The multidisciplinary work between the areas of human movement and ergonomics has also played an important role in the development of techniques for sit-skiing and sit-ski devices, respectively. The confidence provided by the synergic of these professionals has allowed the Alpine

Ski athlete greater understanding of the best use of their equipment, shorter adaptation time, improved performances, increased cognitive capacity, and greater personal satisfaction.

To perform well using a sit-ski, motor strength is needed and a good interaction between the user and equipment. Therefore, the characteristics of the device itself, the manner in which it is used by the skier, and the body posture taken by the athlete while Alpine Skiing are determinant factors for their better performance, establishing a greater efficiency in the man/machine system. It is important to observe that the development of methods and materials geared towards sit-skiers should respect some basic premises, especially in relation to specificity, individuality and adaptation.

It is possible to say that sit-ski was originally created for leisure activities and social inclusion of people with special needs, but nowadays it has become an important Paralympic sport, which has grown in the world sports scene, and gone on to have a vanguard role in the development of the science of training and sports materials and devices.

### 6.5 Sit-skier, Social and Psychological Attitude

The developmental path of the sit-ski has been very relevant from a sports and technological perspective throughout its evolution, but the social and psychological context has also been important since the beginning of its existence. Historical facts began the development of the sit-ski, since it was precisely in the post-war period that Alpine Skiing for disabled people found its application. Initially, it was established in a more participative/inclusive context, but later on went on to assume a more competitive character. It was from 1984 and the Winter Paralympic Games in Innsbruck, Austria, that the sit-ski started aiming not only for participation as a sports modality in competitions, but also concentrated on the performance of the athletes in the events. It is thought that the inclusion of this type of sport in competitive events has an important role in the motivation and rehabilitation process of people with special needs, with this function acting in such a way as to improve their quality of life.

The main focus of this sport that once was the participation, inclusion and rehabilitation of physically or mentally disabled persons, is gradually giving way to competitive ideals with an emphasis on performance. Although the inclusive nature of the sport increased, the growing emphasis on performance and competition that is linked in Alpine Skiing to speed, has brought forward a number of factors that compromise the safety, physical integrity and health of participants. In some cases, this is even at the expense of ethics being ignored by sports participants in an attempt to achieve good results and gain victory, as has been observed by the presence of doping in major competitions, something that breaks entirely from the ideals of the sport.

Even though this new competitive objective brings with it potential risk to the physical integrity of the person with disability, there is a relative acceptance of this due to the pleasure generated by the sense of freedom of movement, the speed and the environment where Alpine Skiing is practiced. This new identity and the success of the sport is a measure that from a cognitive, psychological and social point of view motivates its participants and audience to the present day.

Alpine Skiing and the adapted equipment used has gradually provided the means to improve the physical and mental health of people with special needs, giving accessibility and reintegration into society.

It is also possible to see other aspects derived from the sit-ski that are not tied directly to performance of the sport itself. It can be said from a psychological point of view that the participants begin to develop a positive self-image and a "can do" attitude. This positive cycle of thoughts transfers itself to other aspects of daily life, such as educational or working. The practice of Alpine Skiing in the specific context of the sport (extreme sport) and by the philosophy of a sport that involves equipment preparation, travel to the practice location and the very environment itself, offers special opportunities among the participants for integration (Pringle 1987)**.**

Some individuals who initially embraced the sit-ski solely for leisure and subsequently, for competitive purposes, have come to realise that this activity has also provided for their physical, mental and social wellbeing, having the potential to improve their quality of life. With the modifications that have happened through sport, we have become more interested and engaged in the activities that this type of sport has promoted (international competition systems, athlete classification, equipment development and training methods), giving those involved a different social status.

### 6.6 Possibilities of Adapted Physical Activities

From the moment a person is subject to any kind of physical impairment, this deficiency results in a motor dysfunction, which is accompanied by a series of physical, cognitive and psychological change that requires an entire process of motor and behavioural relearning.

Taking into account the height and level of the motor lesion, a person affected by an SCI has several movement, sport and rehabilitation exercises that are still possible. The mobility of a paraplegic person may take on many different forms (Adams *et al.*, 1985). For example, in the game of volleyball a person can move the body along the floor in a more primitive or rudimentary form of locomotion, whilst some people may adopt the use of walking sticks to retain biped movement that allows them to play football, and others use more sophisticated resources such as a wheelchair or sit-ski that are used in many different competitive sports (basketball, tennis, rugby, alpine and nordic skiing). The physical characteristics of the aquatic environment also allows the exploration of a large range of activities where the athlete can either move in the water as happens in swimming and diving, or on the water as happens in canoeing and other water sports suitable for people in the seated position, with these being ideal for WC dependents.

For people with amputation or dysmelia, depending on the level of amputation (partial or total), the absence of a limb can make their participation in a sport either impossible or difficult, or at the very least may interfere with their taking part, depending on the type of sport chosen. Athletics can be added to the list of adapted official sports presented so far in which people with an amputation can participate. The performance in those official sports practiced by people with special needs can in some cases be of a very close standard to the equivalent events of the Olympic athletes. In certain situations the athlete with disability may even surpass the performances of able-bodied athletes, as can be observed in the 400m track event where participants can compete using carbon fibre prostheses, an event in which Oscar Pistorius has results that are directly comparable to Olympic athletes. The process of learning is very important for both individuals with paraplegia and those with amputations, namely, how to use the remaining muscles. In a more advanced adaptation stage, it is important to establish a training program for the development of motor abilities based on the new body perception of the individual and their interaction with the equipment used. There is a need to exercise the muscles to enhance the musculature of the area not affected by the injury, and also those muscles that remain attached to the area of amputation, which will help with adaptation to the prosthesis. It is also essential to do activities that will enhance the lateral, longitudinal and anterior-posterior balance in WC dependents or in unilateral amputees.

In general terms, all adaptable and recreational sports should be offered to people with special needs. These activities should be above all related to pleasure, their body awareness and cognition. Performance of tasks related to body image where the special dimensions of the body and laterality are worked should also be motivated. Together with the initial adaptation and physical stimulation, it is important to start a basic fitness program. Water activities that can be undertaken by people with different physical deficiencies offer a series of features that are suitable for adapted work in different phases of the rehabilitation process.

In the initial adaptive phase and in cases of more severe physical deficiencies, the simple immersion in water at an adequate temperature[5] will allow some physical and physiological reactions, leading in the majority of cases to a state of wellbeing for the person involved. It should be remembered that in a liquid medium, due to its physical characteristics and the presence of buoyancy, it gives the body support and the possibility of movement in the three body axes. In time, as an individual becomes more adapted to the liquid medium, activities that permit changes in body position should be explored. Additionally, swimming movements should be encouraged, giving a workout of dynamic and static balance, irrespective of whether the person is immersed in or is on the water inside a kayak.

The aquatic environment offers the advantages of its well known features such as pressure, density and temperature, which serve to increase venous return, relax the musculature and reduce spasms, improve muscle and joint pain, decompress the vertebral column, and increase local muscle resistance. It also allows the person performing the focused training or conditioning activity through swimming to carry out exercises in different positions (prone, supine, lateral), as well as respiratory muscle endurance training. The benefits of swimming for people with special needs are well known, but it is important to emphasise that it should also be a part of the training routine for alpine skiers as it

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**5** Adequate temperature **-** Approximately 31.5ºC, the same temperature used in aquatic activities with babies.

will help improve their posture and performance. Currently, however, it is not seen as an intrinsic part of the training routine for alpine skiers.

With a higher degree of specificity for mobility or the possibility of trainable movement, and seeking improved aerobic performance for both users of wheelchairs and sit-skis, there was an attempt to adapt principles of the Pilates method and some exercises and equipment for WC dependent people. This could also be applied to skiers with partial or total amputation of an upper limb, as although they have little change in leg control, there still exists an imbalance in the body as a whole. These adaptations were aimed at developing more the part of their body that would give better control of all the possible movements of a wheelchair and sit-ski, and also better control of the trunk, leading to a reduction in the fear of falling and an increase in confidence through greater control over the equipment. Therefore, it would be advisable to begin the training with requiring the athlete to perform movements that can gradually have the degree of demand increased, and seeking to guide them as to how to fall and get up correctly.

The seated skier needs to carry out intensive body workouts that require the use of different muscle groups (neck, upper limbs and trunk) to assist in keeping the balance when in competition conditions, assuming the best body support position for a faster and more efficient performance by promoting trunk movements with precise lateral flexions used to control directional manoeuvres (Kaps, Nachbauer , Mössner, 1996).

### 6.7 Pilates® Method: Coping with Handicapped Sport

The Pilates® method was developed by Joseph Hubertus Pilates (born in 1880 in Mönchengladbach - Germany) in the beginning of the 1920s. Pilates had spent a childhood fighting against severe asthma, as well as rheumatism and rickets. His personal fight for quality of life led him to develop this method of multidisciplinary training that was influenced by several different sports, such as boxing, gymnastics, yoga and alpine skiing (Traczinski; Polster, 2009).

Pilates® as a training method is based on 7 principles: Control, Concentration, Power House[6], Coordination, Respiration (diaphragmatic[7]), Fluidity and Precision. Altogether they aim to stimulate the body to work out its muscles, bone structures and organs in an efficient way (efficient movements expend less energy to perform specific exercise). The 7 principles are described below (Menezes, 2000):

[6]Power House: it is the core strength of the body that coordinates the respiratory mechanics of the diaphragm, with synergic action with the abdominal, gluteo, pelvic and lumbar muscles, aiming to stabilise the vertebral column during exercise.
[7]Diaphragmatic Respiration: This produces pressure in the abdomen that will act in a direct and efficient form in order to enhance the digestive process. It would be comparable to a healthy massage on the abdominal organs (e.g. liver, kidneys), increasing the secretions that they produce. In addition, the respiration influences the distribution of toxins found in the body, altering the residue, stabilising organic functions and strengthening organs that are debilitated.

**Control -** this consists of the absence of any unplanned movements that are casual or automatic. Each movement has a function for the performance of an exercise. Efficient movements protect the body against injury.

**Concentration -** every exercise should be performed consciously and rhythmically between diaphragmatic respiration, and muscles should be controlled during the performance of a series of exercises.

**Power House -** this name was given by Joseph Pilates and consists of the body core muscles of the abdomen, lumbar, pelvis and gluteus. All the required energy for exercise begins in these areas of the body and flow to the extremities. In this way, all the muscles that constitute the power house act as a belt in the lumbar region, stabilising the vertebral column against possible muscle and structural injury.

**Coordination -** it is the harmonic performance between movements, respiration and the recruitment of the muscles needed for a specific exercise.

**Respiration -** the respiratory technique proposed by this method (inhale through the nose and exhale through the mouth) stimulates the use of the diaphragm during respiration (inspiration expands the chest wall and expiration brings the ribs together again). Through a deep and rhythmic respiration, the person performing Pilates® oxygenates their muscles constantly, whilst at the same time learning to control respiration in a more conscious form.

**Fluidity -** there are no isolated movements in the Pilates® method as the body does not function naturally in this way, but with continuous fluid movements that come from the Power House and are given rhythm by respiration, flowing to the body extremities.

**Precision -** concentration during the performance of a movement is essential and also helps with the synchronisation between diaphragmatic respiration and the specific muscle activity for the performance of an exercise. Self knowledge of the body helps the person conducting Pilates to perform precise exercises that optimise muscle energy.

The Pilates® method also emphasises the importance that the mind exerts over the body, as Joseph believed that any and every movement started through impulses and stimuli in the brain would control stimuli in the body. This relationship between the mind and body was called "Contrology" by him, and is the conscious control of the muscle movements of the body (Pilates & Miller, 2008). It is the correct use and application of the most important principles of strength (resulting from a muscle explosion) acting in every segment of the body with the complete knowledge of its functional mechanisms. The understanding of this principle allows the optimization of the body energy needed for movements in different states, such as active, rest or sleeping (Menezes, 2000).

The Pilates® method of training is based on a program of muscle stimulation that can vary between dynamic and static training, depending on the objective of each participant. Many exercises of this method must be performed in the supine position with the intention of reducing the impact on the joints that support the body, such as the vertebral column, which allows rehabilitation of the sacral lumbar region and its muscles, joints and ligaments. The training can also vary in intensity (there are 3 levels of exercise complexity - basic, intermediate and advanced), duration (10min, 15min, 30min or 1 hour), and variations in type of exercises, such as series on the floor, mixed (floor plus equipment), or exercise series only using specific Pilates® equipment (in general training used to correct muscle imbalance), such as the Cadillac and Reformer.

The basic training system includes a program of exercises that strengthen the abdominal and paravertebral musculature, and muscles that act in the extension and flexion of the trunk. It also includes exercises that enhance the perception of body balance, as well as bilateral and global exercise for the body. In the intermediate training system there is a gradual introduction of exercises that promote the flexion and extension of the trunk at different levels of the vertebral column, as well as exercises that aim to enhance the balance relationship between agonist and antagonist muscles. In the advanced training system the exercise series include coordination, equilibrium and strength activities performed simultaneously with the aim of improving global motor self-awareness.

The principle characteristic of the Pilates® method when applied to people with special needs is based on the adaptability of a routine of exercise that can be used on the floor, with or without aid equipment (Appendix F), such as the *Medicine ball, Roller, Magic-circles*, or even other equipment such as *Cadillac, Reformer, Barrel or Stability Chair.* The benefits of a routine of Pilates exercises extend beyond the group of body muscles, since the method also stimulates vital organs due to the recruitment of deep muscles in different body positions (i.e. supine and seated) adopted during exercise.

Pilates aims to empower individuals with disability or even those with a partial amputation to better use their potential through the development of exercise routines or adaptive equipment (initially hospital beds), in such a way that they can perform independent daily activities. Based on this, Joseph created several pieces of equipment aimed at the rehabilitation of people with physical and functional difficulties (equipment that allows unilateral workouts - for example, only the right or left upper limb in the case of amputees), as this method aims to improve the quality and mechanical efficiency of the body, even in people with reduced mobility.

According to Pilates, the users of this method benefit from the improvement of bodily self-awareness, as well as improvements in the function of the circulatory, respiratory, digestive, reproductive and excretion systems; force and resistance of muscles in general; static and dynamic balance; development of functional and motor abilities used in daily activities; motor coordination and postural alignment. It also provides and motivates experience with the user's possibilities, potentialities and limitations, and motivates independence and body autonomy (Massey, 2011).

## 7. Accessibility and Social Inclusion

### 7.1 Accessibility

The concept of accessibility, according to Brazilian law 10.098 from 19th December 2000, is the possibility and scope for use with security and autonomy of spaces, urban furniture and equipment, buildings, transport, and systems and means of communication for people with disabilities or reduced mobility. According to the United Nations, accessibility is the process of achieving equal opportunities in all spheres of society. The consideration of the term accessibility cannot be dictated by mere reasons of solidarity, but above all, by a conception of a society where everyone should participate with the right to equality and according to their own characteristics (Condorcet, 2006).

The origin of the term accessibility, referring to the condition of access for people with disability, was given through the physical rehabilitation services and professionals at the end of the 1940's (Sassaki, 2006). The phase of integration emerged in this period from the reintegration of rehabilitated adults into their own families, the work place, and into the wider community. The social inclusion phase would take about 40 years to surface and counter the concept of integration. From 1981 onwards and with the advent of the International Year of Disabled Persons, worldwide campaigns were developed to alert society about the physical and social barriers that exist, as well as the requirements for their elimination. In the 1990's, it became evident that accessibility should follow the paradigm of universality, whereby not just those with a disability but everyone was contemplated by projects focused on the functionality of environments, means of transport and the tools required for everyday life.

Accessibility has to assume a prominent role in a society, enabling greater equality of opportunities in education, work, leisure and culture (Maior, 2004) and particularly a better existence. The ease, speed and elimination of physical barriers and social resistance make it possible to access many different experiences and ways of learning, socialising and leisure. This can open wide a universe of opportunities to develop for those people whose autonomy is conditional. In this way, the concept of accessibility has evolved into a wider meaning, benefiting a much larger number of people excluded from the process where the motto becomes either a better quality of life or the elimination of a poor quality of life (Queiroz, 2006).

### 7.2 Social Inclusion

To include is to take part, to insert, to introduce, and inclusion is the act or effect of including. This is the set of means and actions that combat the exclusion of the benefits of life in society, caused by age, gender, race, socioeconomic status, educational level, geographic origin, and the existence of disability. Social inclusion is to provide to the neediest opportunities to access goods and services, within a system that benefits everyone and not just the most favoured from an economic and/or social point of view within that society.

### 7.2.1 Social Inclusion of People with Special Needs

The social inclusion of people with special needs should be no different from that of non-disabled people. Their inclusion maintains their participation as active members of a social, economic and political life, assuring their rights within Society, the State and Public Life. This in turn helps society to encompass people from very different situations in relation to their level of participative ability and intelligence, allowing them to have their own rights, and fulfil their capabilities and needs.

According to the Universal Declaration of Human rights as approved by the United Nations (UN) in 1948, in articles 25, 26, 27 and 28 relating to Social Rights, everyone has the right to food, housing, health, social welfare and care, education and culture, as well as the right to participate in the benefits of scientific development. These rights should be strengthened within the society and state by acting on the principle of there being an interdependent association between them. A lack of respect or commitment to these rights will result in a consequent weakening in the rights of everyone within that society, including those of people with special needs.

The social inclusion of these people must, therefore, respect the fundamental rights of all human beings. However, it is important to understand that the existence of these special needs will make this group different from the general population as a whole and as a result there will be the need for creation of special conditions that will allow them to develop a social, economic and cultural well-being.

As such, in 1975 the UN established the Declaration on the Rights of Persons with Disabilities that sought to address the right of citizenship and welfare for this group, assuring them of the rights mentioned below, which are also applicable to the volunteers of this study.

- The essential right to human dignity. People with special needs, independent of the nature or level of their disability, have the same rights as other citizens, which translates into the right to a decent and as normal a life as possible.
- People with special needs have the right to develop skills that will help them become more self confident.
- People with special needs should have rights to medical, psychological and recuperative treatments, such as prostheses and orthoses, with the aim of rehabilitation. They should also have access to services that will help them develop skills to promote their social integration.
- People with special needs have the right to economic and social safety, and to live with dignity. They have the right, according to their capacities, to employment or participation in a paid occupation.
- People with special needs should have the right for their unique requirements to be included in the social and economic planning of a society.
- People with special needs have the right to live with their families and to participate in social activities. They should not be submitted, even within their own homes, to discriminatory treatment, unless this is necessary for the improvement of their well-being. If there is a need for an individual to

be permanently institutionalised, the environment and conditions of that institution should adhere as closely as possible to those that could be considered as giving a normal life.

It can be seen that the social inclusion of people with special needs depends on their being recognised as people who have special needs that create specific rights, the protection and performance of which depend on the fulfilment of basic human rights.

#### 7.2.2 The Evaluation Process of Para-athletes in the Social Inclusion of People with Special Needs

In order for the evaluation process of para-athletes to promote the social inclusion of people with special needs, it must be done periodically and systematically, with the information gained being disseminated in a dynamic and efficient way through mass communication. The theoretical content of the findings should be easy to comprehend and very practical, enabling those people under evaluation to learn their limits and the possibilities in need of development. It is important that during the process of evaluation the person in question performs the test to the best of their abilities, using this moment as a learning opportunity to increase self-awareness, with this experience also being transmitted for the benefit of the peer group.

It is evident that the evaluative process creates tensions for the person being evaluated and that the main changes will come as an answer to the process as a whole, independent of the findings obtained (positive/negative/neutral). The evaluator should be concerned with supporting the individual learning based on the characteristics of each case, and trying to promote independence and individual autonomy, whilst at the same time encouraging the possibility of team work, as can be seen in such sports as rowing or wheelchair basketball. The person with special needs should be seen in terms of their potential, skills, intelligence and aptitude.

#### 7.2.3 The Role of the Media in the Inclusion of Para-athletes

Until fairly recently a disability would have been considered as a factor for exclusion, however, nowadays this same deficiency can lead to a prominent role in the world of sport due to the investment and dedication of some individuals or the flexibility of some types of sports, as found in radical ones. In the last decade, adapted sports have achieved an undeniable and irreversible role in society, thanks to the investment they have received and their consequent evolution.

The development of new technologies, techniques, methods and their combinations have given many possibilities to people with special needs. The astonishing sporting performances of some para-athletes have motivated inevitable comparisons with able bodied athletes, which leads us to reflect on the way that Paralympic sports have developed. Experts in this area consider that sporting performances during the upcoming Paralympic games in 2016 may even surpass the accomplishments of the athletes without disabilities (Olympic Games), citing in particular the 400m athletics race. This can motivate discussions regarding the possible advantages that paralympic athletes may now have as a result of technology advances that have led to several beneficial adaptations. Indeed, some people consider this to be a form of technological doping.

The media, due to its rapid and extensive ability to disseminate news, has strengthened the image of athletes with special needs. It has promoted them by frequently publishing interviews, articles and news items related to them. The media has also promoted the marketing of these athletes in different sports by the creation of special awards, for example with two athletes being chosen in 2011 as the best athlete of the year with special needs.

Additionally, the media has found through Paralympic sports an efficient propaganda platform, and has offered its clients the possibility of linking the company image to diverse elements, presented in a descending order of importance in a recent study (Hubert, 2011). The sponsorship of disabled athletes, the improvement in company image from investing in adapted sport, and social responsibility, among other reasons, are those that would motivate large companies to invest in adapted sport.

The most recent result of successful investment made using this new advertising platform can be seen from the numbers of transmissions linked to the Summer Olympic Games held in London from 29$^{th}$ August to 9$^{th}$ September 2012, with according to the IPC, the London Games proving to have been a great success for online broadcasting. As an example of this and to better understand the situation, the IPC uploaded during the Olympic Games over 1000 hours of sporting action to its YouTube channel, www.youtube.com/paralympicsporttv, nearly 2 million people visited the website www.paralympic.org and there were close to 9 million views of videos featuring London 2012 sporting action, as well as coverage of the Ceremonies in full. Craig Spence, the IPC's Director of Communications, said: "*We said prior to the Games that we expected London 2012 to be a digital Games, however even these numbers have surpassed our expectations*". By embracing new technologies and media, it is not just the IPC who enjoyed astronomical figures during the greatest Paralympic Games ever, but the international sport federations, National Paralympic Committees and London Organizing Committee of Olympic Games and Paralympic Games also benefitted.

The first day of competition saw more visitors to the website than for the entire Beijing Games, a trend that continued throughout London 2012. More than 780 hours of live sport were broadcast on paralympic.org throughout London 2012 across five channels, with commentary in English and Spanish. An innovative new SMART player, provided by Atos, the IPC's worldwide IT partner, proved extremely popular with visitors enjoying the opportunity to watch live action, results, statistics and social media in one integrated window.

The IPC's official Facebook group page, www.facebook.com/ParalympicGames, grew by 130% during the Games and now has over 136,000 likes. Athletes also recorded significant growths in their social media followings the results of their performances. During the Paralympic Games, the IPC's Facebook pages had over 82 million views from 24 million users with the top five countries being USA, Italy, France, UK and Canada.

# III. INTRODUCTION TO THE RESULTS, HUMAN PERFORMANCE & DISCUSSION

## INTRODUCTION TO THE RESULTS

Before presenting the individual outcomes for the athletes in question, it was decided to bring together some of the results gathered for all the athletes from the *DPS* that participated in the study, such as for example, anthropometric measurements. Table I shows the order of participation for the first evaluative session (Vinagre *et al*, 2011), whilst Table II shows that of the second evaluative campaign. Together, they summarize the anthropometric profile of the volunteers directly involved in the collection of study data.

It is important to highlight that the criteria used when referring to the individual results that follow this general introduction, is related to the degree of volunteer involvement with the evaluation process as a whole. As such, case number 1 brings together the greatest volume of information, whereas case number 7 presents the least.

**Table I: Anthropometric Data Collection in 2010**

| Skier | Sex | Age | Class | Height cm | Weight kg | BMI $kg/m^2$ | Seated Height | Cormic Index | Span cm | Relative Span |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | M | 26 | LW 11, Sit | 160 | 62 | 24.21 | --- | --- | --- | --- |
| 2 | F | 17 | LW 10/2, Sit | 150 | 47 | 20.89 | --- | --- | --- | --- |
| 3 | M | 25 | LW 10-1, Sit | 183 | 63 | 18.81 | --- | --- | --- | --- |
| 4 | M | 29 | LW 12/1, Sit | 185 | 73 | 21.33 | --- | --- | --- | --- |
| 5 | F | 21 | LW 6/8-2, Stand | 163 | 59.5 | 22.39 | --- | --- | --- | --- |
| 6 | M | 38 | LW 10/2, Sit | 173 | 75 | 25.06 | --- | --- | --- | --- |
| 7 | M | 40 | LW 5/7-2, Stand | 185 | 86 | 25.13 | --- | --- | --- | --- |

**Table II: Anthropometric Data Collection in 2011**

| Skier | Sex | Age | Class | Height cm | Weight Kg | BMI $Kg/m^2$ | Seated Height | Cormic Index | Span cm | Relative Span |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | M | 27 | LW 11, Sit | 160 | 59.5 | 23.24 | 116 | 72.50 Macrocormic | 177.5 | 110.93 |
| 2 | F | 18 | LW 10/2, Sit | 150 | 43 | 19.11 | 107 | 71.33 Macrocormic | 162 | 108 |
| 3 | M | 30 | LW 12/1, Sit | 185 | 73 | 21.33 | 125 | 67.56 Macrocormic | 185 | 100 |
| 4 | M | 26 | LW 10-1, Sit | 183 | 63 | 18.81 | 126.5 | 69.12 Macrocormic | 180 | 98.36 |
| 5 | F | 21 | LW 6/8-2, Stand | 163 | 58 | 21.83 | 129 | 79.14 Macrocormic | 145 | 88.95 |

Anthropometric data collected in the first campaign (Table I) and the second campaign (Table II).

Previously validated protocols were used for the cardiorespiratory testing evaluative sessions, however, no validated protocols existed for the tests conducted in the WT (Vinagre *et al*, 2011). It was decided, therefore, to set the wind velocities bearing in mind the adaptation of the laboratory to the volunteers and their sport, and also taking into consideration the safety of the athletes, and thus, simulated relative wind speeds consistent with those found in the competition environment were used. The maximum possible speed that can be generated by this WT for a configuration involving human subjects is 40m/s (144km/h), but to date, this speed would be unattainable by athletes in this sport. Hence, the choice of 30m/s (108km/h) was more consistent with the initial principles that were adopted. The choice of 10m/s (36km/h) was related to the minimum speed required to provide an aerodynamic downforce, as ultimately, very little resistance would be offered by the athletes at a speed of 5m/s (18km/h). The intermediate value was set at the middle point between the maximum and minimum determined speeds so that an evaluation curve could be constructed.

The manner in which the photographic records taken in the WT and the questionnaire responses are organised and presented, also require prior explanation, so that results can be seen together and the choices that were made can be understood.

## 1. Analysis of Wind Tunnel Photographs

Inspired by the photographic anthropometric technique (body composition and posture analysis) developed by Sheldon (Tsang, Chan, Taylor, 1998), the photograph had role in posture and analysis of data collected in this experiment. Standard photographs (with lateral and frontal view) are taken on the four categorized positions and these images are used as a reference for average value met to each body position/velocity ratio. A photograph camera was positioned on the side of the WT section and had captured stationary images of the skiers. Frontal photos of some skiers in the four selected position were also done as a form to obtain data to the frontal area calculation. But it was possible only after the real test, without wind because the difficulties found to fix the camera in WT facilities during the test and the possibility that the camera would produce turbulence on the air flow, would be undesirable.

### 1.1 Lateral Photos

Three photographs were taken in 30 seconds, where one of them would represent the average value found for the measurements. Organising the information in this way, the final report should present 16 individual photos for the seated athletes (12 lateral and 4 frontal), and 12 individual photos for the standing skiers (9 lateral and 3 frontal), analysing separately the two campaigns conducted. It can be seen from Tables III and IV, however, that it was not always possible to record the desired number of photographs in full for some of the cases due to factors inherent to the will of the researcher.

A set strategy was used for the analysis of photos taken for each position, and this proved useful for the description of all. The images were initially arranged in a block of 6 photographs per position performed, this being one photo for each of the 3 different wind speeds during the 1$^{st}$ campaign, and placing next to them the corresponding images taken during the 2$^{nd}$ campaign. This process was then repeated for the photographs taken with the athletes in the alternate positions. With this arrangement completed, each block of 6 photographs was scrutinised vertically, to analyse alterations in the set position for the 3 distinct wind speeds for each year separately. Subsequently, the images were then examined horizontally, to examine the position of an athlete at a particular wind speed during the 1$^{st}$ campaign and comparing it to the corresponding image taken during the 2$^{nd}$ campaign.

Although this form of organisation was chosen for the photographs in the written report, it was realised that the presentation of a single photograph only for each position/speed could distort the analysis of the evaluation made for each stage of the test, and thus short films were created from the entire sequence of photos taken with the volunteers. In this way the 4 test positions could be observed in a more dynamic way. In this sense, a software (Windows Movie Maker) was used for both campaigns to present all the photos in sequence, varying the interval between the exposition of each photograph, so that a better understanding of the performance of the athletes for each stage evaluated could be made. The slower version allowed us to observe a sequence of photos of 2 in 2 seconds, followed by a version of 1 in 1 second, 0.75 in 0.75s, and finally the quickest version of 0.5 in 0.5s, as presented in Tables III and IV.

It is important to note that the way in which the photograph captions are organised relates to the order the tests were carried out (i.e. T2 is test no. 2), the position performed (i.e. P1 is position 1), the speed at which the test was performed (i.e. S1 is velocity 10m/s), and in the case of the frontal photographs, the photo version in diagram form (i.e. v2 is the version to evaluate the frontal area). This enables us to have a direct and immediate understanding of the captions linked to the photos presented in this section of the study.

**1.2 Frontal Photographs**

Digital photographs were taken from a frontal perspective in order to record from this angle the 4 distinct test positions produced by the athletes, and additionally, to enable the calculation of the frontal area of each individual (Thompson, 2001). This additional step was carried out during the second campaign only, and was made possible using software (Paintshop Pro and Matlab) to determine the frontal area presented by each athlete in the different positions. One of the images from the frontal photographs captured of each skier was taken together with a set scale, to enable the appropriate calibration (metres/pixels) to be made. The silhouette of each athlete could be defined through the use of Paintshop Pro and the number of pixels per square metre determined, with this giving the area in relation to the rest of the photo (white background). It was then possible, using Matlab, to count both the pixels in black and in white, and from this a calculation of the frontal area of the athletes in each of the performed positions was made. This calculation was performed in order to verify the differences between the estimated area and the actual area presented by the athlete being evaluated during each stage of testing.

**Table III – Data Collection from Athletes in Wind Tunnel Experiment - First Campaign**

| Skier | Total Lateral Photos | Lateral Photos | | Frontal Photos | Upright m/s | | | Run m/s | | | Tuck m/s | | | Extra m/s | | | "Photo Film" s | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Written Report | Used as a film | | 10 | 20 | 30 | 10 | 20 | 30 | 10 | 20 | 30 | 10 | 20 | 30 | **2** | **1** | **0.75** | **0.50** |
| 1 | 47 | 12 | 47 | 04 | x | x | x | x | x | x | x | x | x | x | x | x | 94" | 47" | 35" | 23" |
| 2 | 26 | 5 | 26 | -- | - | x | x | - | x | x | - | x | - | - | - | - | 32" | 16" | 12" | 8" |
| 3 | 23 | 6 | 23 | -- | - | x | x | - | x | x | - | x | x | - | - | - | 46" | 23" | 17" | 11" |
| 4 | 43 | 15 | 43 | -- | x | x | x | x | x | x | x | x | x | x | x | x | 68" | 34" | 25" | 17" |
| 5 | 43 | 12 | 43 | 04 | x | x | x | x | x | x | x | x | x | x | x | x | 78" | 39" | 29" | 19" |
| 6 | 39 | 12 | 39 | 04 | x | x | x | x | x | x | x | x | x | x | x | x | 78" | 39" | 29" | 19" |
| 7 | 45 | 10 | 45 | 04 | x | x | x | x | x | x | x | x | x | - | x | - | 72" | 36" | 27" | 18" |
| Total | 266 | 76 | 266 | 16 | 5 | 7 | 7 | 5 | 7 | 7 | 5 | 7 | 6 | 4 | 5 | 4 | | | | |

Number of photos and evaluative processes to which the athletes were submitted, and confirmation of the stages performed by the athletes in Test 2.

**Table IV – Data Collection from Athletes in Wind Tunnel Experiment - Second Campaign**

| Skier | Total Lateral Photos | Lateral Photos | | Frontal Photos | Upright m/s | | | Run m/s | | | Tuck m/s | | | Extra m/s | | | "Photo Film" s | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Written Report | Used as a film | | 10 | 20 | 30 | 10 | 20 | 30 | 10 | 20 | 30 | 10 | 20 | 30 | **2** | **1** | **0.75** | **0.50** |
| 1 | 50 | 12 | 43 | 3 | x | x | x | x | x | x | x | x | x | x | x | x | 86" | 43" | 32" | 21" |
| 2 | 46 | 12 | 46 | 3 | x | x | x | x | x | x | x | x | x | x | x | x | 92" | 46" | 34" | 23" |
| 3 | 43 | 12 | 43 | 4 | x | x | x | x | x | x | x | x | x | x | x | x | 86" | 43" | 32" | 21" |
| 4 | 41 | 12 | 41 | 4 | x | x | x | x | x | x | x | x | x | x | x | x | 82" | 41" | 31" | 20" |
| 5 | 33 | 9 | 12 | 4 | - | - | - | x | x | x | x | x | x | x | x | x | 66" | 33" | 25" | 16" |
| Total | 213 | 57 | 185 | 18 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | | | | |

Number of photos and evaluative processes to which the athletes were submitted, and confirmation of the stages performed by the athletes in Test 3.

### 1.3 Questionnaire Results

During the second campaign only, a subjective evaluation took place in the form of a questionnaire answered by the athletes, and this will now be presented. This tool was applied with the intention of obtaining more detailed information in relation to the tests performed from the impressions of the athletes involved. The questionnaire is formed of three different sections. The first relates to general information regarding athlete training and was answered via electronic means prior to the beginning of the second campaign. The second section refers to the experiment in the WT and was applied *in situ*, before and after the test, and lastly, the third section relates to the spiroergometry test, and was again applied both before and after the test.

The way in which the responses given by the athletes have been organized facilitates a straightforward understanding of the data. It should be remembered that the legend used refers only to those athletes who participated in the second campaign (S1, S2, S3, S4 and S5). It can be seen through the answers given by the volunteers (S1, S2 and S5), that their training period commences in May and runs till August. The emphasis on training during these months is centred on physical work (strength, endurance and localised muscular endurance). The frequency of activity is daily, with there being frequent occasions when two forms of training take place in a day, although the sessions do not exceed two hours. Two athletes in particular also take part in leisure activities (swimming, wheelchair basketball) to complement their training routines.

The emphasis of pre-season training prior to the competition period is still centred on physical conditioning work, however, the technical and tactical training specific to Alpine Skiing increases in percentage (approx 40%), as can be seen in the second responses box for question 2 of the questionnaire, related specifically to pre-season training. The frequency of training remains on a daily basis, with two forms of activity regularly taking place, and with some of the technical training sessions exceeding two hours in duration.

The emphasis for training during the competitive season changes with the focus shifting more to technical and tactical training specific to Alpine Skiing, however, physical conditioning work does continue, as can be seen in the table for replies to question 3 of the questionnaire. The training frequency continues on a near daily basis with two different forms of activity taking place. Some of the technical training sessions last for more than two hours.

The post-season workouts are reduced and the average responses given by the athletes suggest that the work centred on physical conditioning remains the most important. The training frequency is reduced on average by 50% to 60% but the length of the sessions remains between 1 to 2 hours.

## I. Questions related to Training

### 1. When do you start your training season?

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | S5 | S1 | | S2 | | | | |

### 2. What is the profile of your training year?

| Period – June/July-September - Summer<br>Vacation and the beginning of the Training Season | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Form** | **Type of Training** | **Period (months)** | | | | **Frequency per Week** | | | | **Duration/ section** | | | |
| | | **S1** | **S2** | **S4** | **S5** | **S1** | **S2** | **S4** | **S5** | **S1** | **S2** | **S4** | **S5** |
| **Bodybuilding** | Power | 1-2 | 3 | 3 | 2.25 | 3x | 2x | 1x | 4x | 1.5-2h | 1h | 1h | 1.5h |
| **Ergometer** | Endurance | 4 | 3 | 3 | 2.25 | 7x | 7-8x | 4x | 1x | 1-2h | 1.5-2h | 2h | 2h/ + |
| **Pilates** | Localized Musc. End. | | 3 | 3 | 2.25 | | 2x | 1x | 3x | | 15-30’ | 1h | 1h |
| **Technique** | Specific | | | 3 | | | | 1x | | | | 1h | |
| **Tactical** | Specific | | | | | | | | | | | | |
| **Track & Field** | Specific/ Endurance | | | | 2.25 | | | | 2x | | 1h | | 1h |
| **Swimming** | Endurance or Leisure | | 3 | | | | 1-2x | | | | | | |
| **WC Basketball** | Leisure | | | 3 | | | | 1x | | | | 2h | |

**WC – Wheelchair**

| Period –Sep/October-December - Autumn<br>Pre-Season Training | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Form** | **Type of Training** | **Period (months)** | | | | **Frequency per Week** | | | | **Duration/ section** | | | |
| | | **S1** | **S2** | **S4** | **S5** | **S1** | **S2** | **S4** | **S5** | **S1** | **S2** | **S4** | **S5** |
| **Bodybuilding** | Power | 1-2 | 3 | 3 | 3.5 | 2-3x | 2x | 2x | 3x | 1.5-2h | 1h | 1h | 1.5h |
| **Ergometer** | Endurance | 5 | 3 | 3 | 3.5 | 4x | 4-5x | 3x | 2x | 1.5h | 1.5-2h | 2h | 2h |
| **Pilates** | Localized Musc. End. | | 3 | | 3.5 | | 2x | | 3x | | 15-30’ | | 1h |
| **Technique** | Specific | 3 | 3 | 3 | 3.5 | 3x | 3x | 2x | 2x/+ | 4h | 2-2.5h | 1h | 4h/+ |
| **Tactical** | Specific | | 3 | 3 | | | 3x | 1x | | | 2-2.5h | 1h | |
| **Track & Field** | Specific/ Endurance | | | 3 | 3.5 | | | 1x | 1x | | | 1h | 1h |
| **Swimming** | Endurance or Leisure | | 3 | | | | 1x | | | | 1h | | |
| **WC Basketball** | Leisure | | | 3 | | | | 1x | | | | 2h | |

### 3. Could you mention how was the training DURING the Competition Season?

| Period – Dec/January-March - Winter<br>Winter Competition Season | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Form** | **Type of Training** | **Period (months)** | | | | **Week Frequency** | | | | **Duration/ section** | | | |
| | | **S1** | **S2** | **S4** | **S5** | **S1** | **S2** | **S4** | **S5** | **S1** | **S2** | **S4** | **S5** |
| **Bodybuilding** | Power | 4 | 3 | 3 | 4 | 1x | 1x | 1x | 1x | 1h | 1h | 1h | 1.5h |
| **Ergometer** | Endurance | 4 | 3 | 3 | 4 | 2x | 4x | 2x | 1x | 1-1.5h | 1h | 2h | 2h |
| **Pilates** | Localized Musc. End. | 4 | 3 | | 4 | 2x | 1-3x | | 1x | 1h | 20’ | | 1h |
| **Technique** | Specific | 4 | 3 | 3 | 4 | 3-4x | 1x | 4x | 3x/+ | 3h | 2-2.5h | 2h | 3h/+ |
| **Tactical** | Specific | 4 | | 3 | | 3-4x | | 3x | | 3h | | 2h | |
| **Track & Field** | Specific/ Endurance | | | 3 | 4 | | | 3x | 1x | | | 2h | 1h |
| **Swimming** | Endurance or Leisure | | | | | | | | | | | | |
| **WC Basketball** | Leisure | | | 3 | | | | 1x | | | | 2h | |

### 4. How was the training AFTER the Competition Season? What have you done?

| Period – Mar/April-June - Spring<br>Post-Winter Competition Season | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Form** | **Type of Training** | **Period (months)** | | | | **Week Frequency** | | | | **Duration/ section** | | | |
| | | **S1** | **S2** | **S4** | **S5** | **S1** | **S2** | **S4** | **S5** | **S1** | **S2** | **S4** | **S5** |
| **Bodybuilding** | Power | | 3 | 3 | 2.25 | | 2x | 2x | 2x | | 1h | 1h | 1.5h |
| **Ergometer** | Endurance | 3 | 3 | 3 | 2.25 | 2-3x | 7x | 3x | 2x | 1-1.5h | 2-2.5h | 2h | 2h/+ |
| **Pilates** | Localized Musc. End. | | 3 | | 2.25 | | 1x | | 2x | | 20’ | | 1h |
| **Technique** | Specific | | | 3 | 1 | | | 2x | 2x | | | 1h | 3h |
| **Tactical** | Specific | | | 3 | | | | 1x | | | | 1h | |
| **Track & Field** | Specific/ Endurance | | | 3 | 2.25 | | | 1x | 2x | | | 1h | 1h |
| **Swimming** | Endurance or Leisure | | 3 | | | | 1-2x | | | | 1h | | |
| **WC Basketball** | Leisure | | | 3 | | | | 1x | | | | 2h | |

### 5. Mark with an “x” those forms of training in which you have taken part since November?

| | **S1** | **S2** | **S5** | | **S1** | **S2** | **S5** |
|---|---|---|---|---|---|---|---|
| **Aerobic Training** | x | x | x | **Tempo Training** | | x | x |
| **Continuous Training** | x | x | x | **Isocinetic** | | | |
| **Anaerobic Training** | x | x | x | **Sprint Training** | | x | |
| **Interval Training** | x | x | x | **Isotonic** | | | |
| **Isometric** | | | x | **Fartlek** | | | |

It is interesting to note from the recorded responses to question number 8 that not one of the volunteers responded negatively in relation to how they felt, suggesting that the study participants had high self-esteem. However, it can be seen from one of the volunteer responses to questions 9 and 10 regarding the perception of discomfort, and aimed only at the sit-skiers, that a degree of pain was felt from routine use of the wheelchair after a couple of hours.

**6. Participation and classification for the Alpine Skiing World Championship Sestriere/Italy**

| Competition | Discipline | | | | | | Classification | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S5 | S1 | S2 | S3 | S4 | S5 |
| World Championship Sestriere/Italy | Slalom | x | x | x | | x | 3 | 1 | -- | | 1 |
| | Giant Slalom | x | x | | x | | 9 | 1 | | 6 | |
| | Super G | x | x | x | | x | 12 | 4 | 14 | | 3 |
| | Down Hill | x | x | x | | x | 7 | 4 | 9 | | 1 |
| | Super-Comb | | | | | x | | | | | 2 |

**7. Have you suffered any accident or hard injury?**

| | Yes, unfortunately I have. | No, I have not. | Competition/ Injury |
|---|---|---|---|
| S1 | | x | |
| S2 | x | | Concussion during World Championship |
| S5 | | x | |

**8. In general, how do you feel?**

| | S1 | S2 | S4 | S5 | | S1 | S2 | S4 | S5 |
|---|---|---|---|---|---|---|---|---|---|
| Healthy | x | x | | x | With a high potential | | x | x | |
| Fit | x | x | | | Powerful | | x | x | x |
| Motivated | x | x | x | x | Hopeful | | x | | |
| Able | x | x | x | | Positive mind | | x | | x |
| Useful | | x | x | | Happy | x | x | | x |

| | S1 | S2 | S4 | S5 | | S1 | S2 | S4 | S5 |
|---|---|---|---|---|---|---|---|---|---|
| Unhealthy | | | | | With a low potential | | | | |
| Exhausted | | | | | Weak | | | | |
| Unmotivated | | | | | Unhopeful | | | | |
| Unable | | | | | Depressed | | | | |
| Useless | | | | | Unhappy | | | | |

**9. How comfortable is your wheelchair during the whole day? (**To be completed by sit skiers only.)

| | | S1 | S2 | S4 |
|---|---|---|---|---|
| 1 | Very Good | | | |
| 2 | Comfortable | x | x | |
| 3 | Well | | | x |
| 4 | Not so comfortable | | | |
| 5 | Uncomfortable | | | |

**10. Do you feel pain? (**Question just for the sit skier.)

| | | S1 | S2 | S4 |
|---|---|---|---|---|
| 1 | I do not feel pain | x | x | |
| 2 | I feel pain/ uncomfortable after 4 hours seated | | | |
| 3 | I feel pain/ uncomfortable after 2 hours seated | | | x |
| 4 | I feel pain/ uncomfortable after 1 hour seated | | | |
| 5 | I feel pain/ uncomfortable after 30 minutes seated | | | |

When looking at the second part of the questionnaire, it can be seen that there is a certain degree of homogeneity about the answers given by the volunteers in relation to the WT tests. However, an exception to this is found in the responses to question number 4 regarding the level of effort demanded by the WT tests, with these showing a greater variation and a lack of consensus.

## II. Questions related the Wind Tunnel assessment – Pre-Test

### 1. In one word, how would be your sport technical performance (Alpine Skiing)?

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Excellent | | | | | |
| 2 | Very Good | | | x | x | x |
| 3 | Good | x | x | | | |
| 4 | Not so good | | | | | |
| 5 | Unsatisfactory | | | | | |

### 2. How would you classify your technical performance now, just before the evaluation, when you compare to the last year assessment?

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Much better than last year | | | | | |
| 2 | Better than last year | x | x | x | x | x |
| 3 | Almost the same than last year | | | | | |
| 4 | Worse than last year | | | | | |
| 5 | Much worse than last year | | | | | |

### 3. How good was your technical performance during the Competition Season?

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Above expectation | | | | | x |
| 2 | Within expectation | x | x | x | x | |
| 3 | Under expectation | | | | | |
| 4 | Frustrating | | | | | |
| 5 | I had no expectation | | | | | |

### 4. How far was the demand of Wind Tunnel Test (November 2010)?

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Exhausting | | | | | |
| 2 | Hard, but acceptable | | | | | x |
| 3 | Difficult | x | | | | |
| 4 | Not so difficult | | x | | x | |
| 5 | Easy | | | x | | |

### 5. What do you mean: is Wind-Tunnel Test important to the Alpine Skiing athletes' assessment?

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Very important | | | | | |
| 2 | Important | x | x | x | | x |
| 3 | Not so important | | | | x | |
| 4 | Indifferent | | | | | |
| 5 | Not important | | | | | |

### 6. Has W-T Test brought results that could influence your skier performance (Nov. 2010)?

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Significantly | | | | | |
| 2 | Yes, but not too much | x | x | x | x | |
| 3 | It did not influence | | | | | |
| 4 | I can not evaluate | | | | | x |
| 5 | I don't care | | | | | |

### 7. How much did Wind-Tunnel Test results collaborate to modify the training of the Ski team?

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Much! We have a completely new form of training | | | | | |
| 2 | Good! We have a lot of innovations in our training | | | | | x |
| 3 | Not too much! We have some adaptations to the usual training | x | x | x | x | |
| 4 | Almost nothing! We have few adaptations to the usual training | | | | | |
| 5 | Nothing, we are still doing the same old things | | | | | |

### 8. How did you feel during Wind Tunnel Test (Nov. 2010)?

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Very Good | | x | x | | |
| 2 | Comfortable | x | | | x | x |
| 3 | Well | | | | | |
| 4 | Not so comfortable | | | | | |
| 5 | Uncomfortable | | | | | |

The questions directed at the volunteers post-test show a relative homogeneity in the responses provided with regards to their receptivity towards this mode of evaluation, and a wider variety of answers in respect of the perceived level of comfort for the different positions performed in the WT up to 30 m/s. This can be seen particularly in question 6 where four different responses were given to the choices.

## II. Questions related to the Wind Tunnel assessment – Post-Test

**1. In one word, how was your sport technical performance in W-T (Alpine Skiing)?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Excellent | | | x | | |
| 2 | Very Good | x | | | x | x |
| 3 | Good | | x | | | |
| 4 | Not so good | | | | | |
| 5 | Unsatisfactory | | | | | |

**2. How far was the demand of Wind Tunnel Test today (12.08.11)?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Exhausting | | | | | |
| 2 | Hard, but acceptable | x | | | | x |
| 3 | Difficult | | | | | |
| 4 | Not so difficult | | x | x | x | |
| 5 | Easy | | | | | |

**3. What do you mean: is Wind-Tunnel Test important to the Alpine Skiing athletes' assessment?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Very important | | | | | |
| 2 | Important | | x | x | x | |
| 3 | Not so important | x | | | | x |
| 4 | Indifferent | | | | | |
| 5 | Not important | | | | | |

**4. Has Wind-Tunnel Test brought results that could influence your skier performance?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Significantly | | | x | | |
| 2 | Yes, but not too much | x | x | | x | x |
| 3 | I don't think so | | | | | |
| 4 | I can not evaluate | | | | | |
| 5 | I don't care | | | | | |

**5. How did you feel during Wind-Tunnel Test today (12.08.11)?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Very Good | | | x | | |
| 2 | Comfortable | x | x | | x | x |
| 3 | Well | | | | | |
| 4 | Not so comfortable | | | | | |
| 5 | Uncomfortable | | | | | |

**6. Which was the most comfortable position to keep during the test at 30 m/s?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Position 1 | | | | x | |
| 2 | Position 2 | | | x | | |
| 3 | Position 3 | x | | | | x |
| 4 | Position 4 | | x | | | |
| 5 | There was no difference | | | | | |

Continuing into the third part of the questionnaire, an uniformity in the responses by the volunteers can be seen for nearly all the questions except for numbers 4 and 6. These questions evaluated the level of demand of the performed test and the benefits of the feedback provided by this type of evaluation, respectively.

## III. Questions related to the Exercise Physiology Assessment – Pre-Testing

**1. In one word, how would be your cardiopulmonary performance?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Excellent | | | | | |
| 2 | Very Good | x | | x | x | x |
| 3 | Good | | x | | | |
| 4 | Sufficient | | | | | |
| 5 | Unsatisfactory | | | | | |

**2. How would you classify your cardiopulmonary performance now, just before the evaluation, when you compare to the last year assessment?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Much better than last year | | | | | |
| 2 | Better than last year | | | x | | |
| 3 | Almost the same than last year | x | x | | x | x |
| 4 | Worse than last year | | | | | |
| 5 | Much worse than last year | | | | | |

**3. How good was your fitness performance (physical condition) during the Competition Season?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Above expectation | | | | | |
| 2 | Within expectation | x | x | x | x | x |
| 3 | Under expectation | | | | | |
| 4 | Frustrating | | | | | |
| 5 | I had no expectation | | | | | |

**4. How far was the demand of Spiroergometry (November 2010)?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Exhausting | | | x | | |
| 2 | Hard, but acceptable | | x | | | |
| 3 | Difficult | x | | | x | x |
| 4 | Not so difficult | | | | | |
| 5 | Easy | | | | | |

**5. What do you mean: is Spiroergometry important to the Alpine Skiing athletes' assessment?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Very important | | x | | | |
| 2 | Important | x | | x | x | |
| 3 | Not so important | | | | | x |
| 4 | Indiferent | | | | | |
| 5 | Not important | | | | | |

**6. How much did Spiroergometry results can influence the specific performance of the skiers (Nov. 2010)?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Significantly | x | | | | |
| 2 | Quite good | | x | | x | |
| 3 | Not too much | | | | | |
| 4 | It did not any difference | | | | | x |
| 5 | I can not evaluate | | | x | | |

**7. How much did Spiroergometry results collaborate to modify the training of the Ski team?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Much! We have a completely new form of training. | | | | | |
| 2 | Good! We have a lot of innovations in our training. | x | x | x | | |
| 3 | Not too much! We have some adaptations to the usual training. | | | | x | x |
| 4 | Almost nothing! We have few adaptations to the usual training. | | | | | |
| 5 | Nothing, we are still doing the same old things. | | | | | |

**8. How did you feel during Spiroergometry (Nov. 2010)?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Very Good | | | | | |
| 2 | Comfortable | x | x | x | | x |
| 3 | Well | | | | | |
| 4 | Not so comfortable | | | | x | |
| 5 | Uncomfortable | | | | | |

It can be seen from the questions directed at the athletes post-test that there is uniformity in nearly all the answers given by the volunteers, except for question 7 that evaluated how well the athletes felt they could breathe during testing, taking into account the trunk position being either in an upright or bent position.

## III. Questions related to the Exercise Physiology Assessment – Post-Testing

**1. In one word, how was your cardiopulmonary performance?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Excellent, above the expectations | | | | | |
| 2 | Very Good | x | | x | | x |
| 3 | Good within the expectations | | x | | x | |
| 4 | Sufficient | | | | | |
| 5 | Unsatisfactory bellow the expectations | | | | | |

**2. How far was the demand of Spiroergometry (13.08.11)?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Exhausting | | | | | |
| 2 | Hard, but acceptable | x | | x | x | x |
| 3 | Difficult | | x | | | |
| 4 | Not so difficult | | | | | |
| 5 | Easy | | | | | |

**3. What do you mean: is Spiroergometry important to the Alpine Skiing athletes' assessment?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Very important | | | | | |
| 2 | Important | x | x | x | x | x |
| 3 | Not so important | | | | | |
| 4 | Indifferent | | | | | |
| 5 | Not important | | | | | |

**4. Has Spiroergometry brought results that could influence your performance in Alpine Skiing?**

| | | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| 1 | Significantly | | | | | |
| 2 | Quite good | x | x | | x | |
| 3 | Not too much | | | x | | x |
| 4 | Did not make a difference | | | | | |
| 5 | I cannot evaluate | | | | | |

**5. How comfortable was the test in general?**

| Trunk in the vertical position | S1 | S2 | S3 | S4 | S5 | Trunk in the bent position | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No discomfort | | | x | | | No discomfort | | | | | |
| Some discomfort | x | x | | x | x | Some discomfort | | x | x | x | x |
| Moderate discomfort | | | | | | Moderate discomfort | x | | | | |
| High discomfort | | | | | | High discomfort | | | | | |
| Discomfort unbearable | | | | | | Discomfort unbearable | | | | | |

**6. How good could you perform during the test?**

| Trunk in the vertical position | S1 | S2 | S3 | S4 | S5 | Trunk in the bent position | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Excellent, above expectations | | | | | | Excellent, above expectations | | | | | |
| Very Good | x | | x | x | x | Very Good | | | x | x | x |
| Good within the expectations | | x | | | | Good within the expectations | x | x | | | |
| Sufficient | | | | | | Sufficient | | | | | |
| Unsatisfactory, below expectations | | | | | | Unsatisfactory, below expectations | | | | | |

**7. How well could you breath during the test?**

| Trunk in the vertical position | S1 | S2 | S3 | S4 | S5 | Trunk in the bent position | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Very Good | | | x | x | | Very Good | | | | x | |
| Good | | x | | | x | Good | | | x | | x |
| Well | | | | | | Well | x | x | | | |
| Not so good | x | | | | | Not so good | | | | | |
| Very bad | | | | | | Very bad | | | | | |
| | S1 | S2 | S3 | S4 | S5 | | S1 | S2 | S3 | S4 | S5 |
| Comfortable | | x | x | | | Comfortable | | | x | | |
| Not so comfortable | x | | | | | Not so comfortable | x | x | | | |
| Uncomfortable | | | | | | Uncomfortable | | | | | |

## 2. Case Study

### 2.1 Case number 1/ Volunteer (C1)

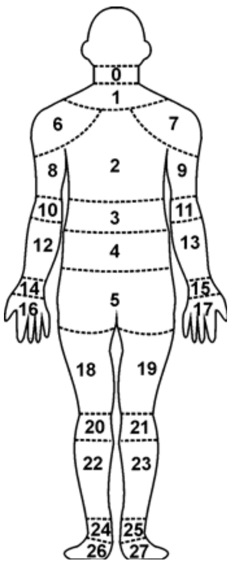
The first case is an athlete from the male Alpine Ski team, born on 13/06/84, and having a disability classification of LW11 in the sitting skiers (monoskiers) category. He suffered a car accident at age 9, whereby he fractured the twelfth thoracic vertebra (T12) and this resulted in his becoming paraplegic. His deficiency is considered to be moderate, preventing movement of his legs and part of his body trunk. He has practised monoskiing since 1995 and has trained for competitions with the *DPS* since 2004, where he has obtained satisfactory results in the sport and his performance has improved with each passing year.

Anthropometric measurements of the participants were collected for both campaigns, and it can be seen from Tables I and II (p.78) that C1 is 160cm tall and weighed 59.5kg at his last evaluation, giving him a Body Mass Index of 23.24 kg/m$^2$. Measurements of seated height and arm-span of the participant were also taken during the latter evaluative campaign, which allowed his Cormic Index and relative arm-span to be determined. The individual assessment of C1 also included important information related to his perceived discomfort through use of the Body Discomfort Diagram presented in Figure 1.

**Figure 1: Body Discomfort Diagram**

**Body Discomfort Diagram**

| | |
|---|---|
| 0. Neck | **1** 2 3 4 5 |
| 1. Cervical | **1** 2 3 4 5 |
| 2. High back | **1** 2 3 4 5 |
| 3. Middle back | 1 **2** 3 4 5 |
| 4. Low back | 1 2 **3 4** 5 |
| 5. Hip | 1 2 3 **4 5** |
| 6. R. Shoulder | **1** 2 3 4 5 |
| 7. L. Shoulder | **1** 2 3 4 5 |
| 8. R. Arm | **1** 2 3 4 5 |
| 9. L. Arm | **1** 2 3 4 5 |
| 10. R. Elbow | **1** 2 3 4 5 |
| 11. L. Elbow | **1** 2 3 4 5 |
| 12. R. Forearm | **1** 2 3 4 5 |
| 13. L. Forearm | **1** 2 3 4 5 |
| 14. R. Wrist | **1** 2 3 4 5 |
| 15. L. Wrist | **1** 2 3 4 5 |
| 16. R. Hand | **1** 2 3 4 5 |




According to Corlett and Wilson, 1986

**1. No discomfort**
**2. Some discomfort**
**3. Moderate discomfort**
**4. High discomfort**
**5. Unbearable discomfort**

| | |
|---|---|
| 17. L. Hand | **1** 2 3 4 5 |
| 18. R. Thigh | 1 2 3 4 **5** |
| 19. L. Thigh | 1 2 3 4 **5** |
| 20. R. Knee | 1 2 3 4 **5** |
| 21. L. Knee | 1 2 3 4 **5** |
| 22. R. Leg | 1 2 3 4 **5** |
| 23. L. Leg | 1 2 3 4 **5** |
| 24. R. Ankle | 1 2 3 4 **5** |
| 25. L. Ankle | 1 2 3 4 **5** |
| 26. R. Foot | 1 2 3 4 **5** |
| 27. L. Foot | 1 2 3 4 **5** |

#### 2.1.1 Tests

C1 was the first participant to complete both the treadmill and the wind tunnel tests for the first campaign, even though no pre-determined order of participation had been arranged, which demonstrates the motivation on the part of the athlete. C1 followed the standard protocol in accordance with the pre-planned steps for the treadmill spiroergometry evaluations scheduled for test sessions 1 and 4, and served as a reference for the other athletes who had never taken part in such a procedure. This was not the case, however, for test sessions 2 and 3 involving the wind tunnel as C1 was not familiar with this procedure and had not taken part in such an evaluation before.

**Cardiopulmonary Test**

**Preparations; Control; Immediately before, During, After the test; Recovery**

C1 was the first athlete to take up position on the treadmill to begin the evaluation section, possibly as he had completed such testing in previous years and was therefore familiar with the equipment, although he was not the only athlete to have this prior experience. The initial load encountered, which refers to the equilibrium point of the athlete with his wheelchair, was 5.68N for test number 1 (T1) and 4.52N for test number 4 (T4). The blood sample taken before T1 showed a lactic acid concentration of 1.1mmol/L, whereas the reading prior to T4 was 2mmol/L. The cardiac electrical activity of the volunteer was monitored closely during testing, together with the consistency of the recorded physiological values to ensure that none of the monitored recordings showed any warnings signs. Both of the test sessions were brought to an end at the request of the athlete, having reached his limit of endurance. New blood samples were collected immediately at test end, and again 3min. and 5min. after the end, with these values being presented in Tables 1 and 2. After removal of the mouthpiece/mask, the participant was asked about the nature and intensity of the limiting symptoms, with the replies being recorded on a standard form. Routine post-tests were conducted during the recovery period to ensure that both Electrocardiogram (ECG) and systemic blood pressure measurements returned to normal before the release of the volunteer, and the official ending of the test session.

**Results of Cardiopulmonary Tests 1 and 4**

The volunteer was required to pass a pre-test for both evaluative campaigns before being allowed to take part in the actual testing session. The oxygen consumption ($\dot{V}O_2$), heart rate (HR) and load values obtained from the spiroergometry are listed in Table 1 and 2 and in Figures 2, 3, 4 and 5.

**Tables 1 and 2 – Results of Tests 1 and 4 for Athlete C1**

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 78 | 290 | 0.895 | 99.53 | 0.00 | 1.1 |
| 3 | 20 | 111 | 858 | 0.954 | 298.71 | 6.70 | |
| 3 | 40 | 115 | 1218 | 0.981 | 427.11 | 9.37 | |
| 3 | 60 | 147 | 1561 | 1.112 | 564.90 | 10.62 | |
| 3 | 80 | 176 | 1922 | 1.231 | 715.00 | 11.19 | |
| 1min. 30s | 100 | 194 | 2137 | 1.347 | 816.19 | 12.25 | |
| | | | | | | | |
| after Stop | | 198 | | | | | 10.1 |
| 1 | | 168 | | | | | |
| 2 | | 137 | | | | | |
| 3 | | 113 | | | | | 10.1 |
| 4 | | 110 | | | | | |
| 5 | | 108 | | | | | 9.3 |

$P_N$ – Mechanical output, HR - Heart Rate, $VO_2$ - Oxygen Consumption, RQ - Respiratory Quotient, $P_B$ Gross output, "e" - equivalent $P_N$/ $P_B$, LA – Lactate.

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 83 | 324 | 0.941 | 112.34 | 0.00 | 2.00 |
| 3 | 20 | 112 | 854 | 1.001 | 300.82 | 6.65 | |
| 3 | 40 | 129 | 1052 | 1.002 | 370.54 | 10.80 | |
| 3 | 60 | 149 | 1515 | 1.140 | 551.90 | 10.87 | |
| 3 | 80 | 175 | 1828 | 1.286 | 688.74 | 11.62 | |
| 1min. 36s | 100 | 194 | 1958 | 1.564 | 784.42 | 12.75 | |
| | | | | | | | |
| after Stop | | 191 | | | | | 9.6 |
| 1 | | 163 | | | | | |
| 2 | | 133 | | | | | |
| 3 | | 111 | | | | | 9.1 |
| 4 | | 109 | | | | | |
| 5 | | 105 | | | | | 8.4 |

$P_N$ – Mechanical output, HR - Heart Rate, $VO_2$ - Oxygen Consumption, RQ - Respiratory Quotient, $P_B$ Gross output, “e” - equivalent $P_N$/ $P_B$, LA – Lactate.

## Figures 2, 3, 4 and 5 – Results of Spiroergometry (tests 1 & 4) for athlete C1

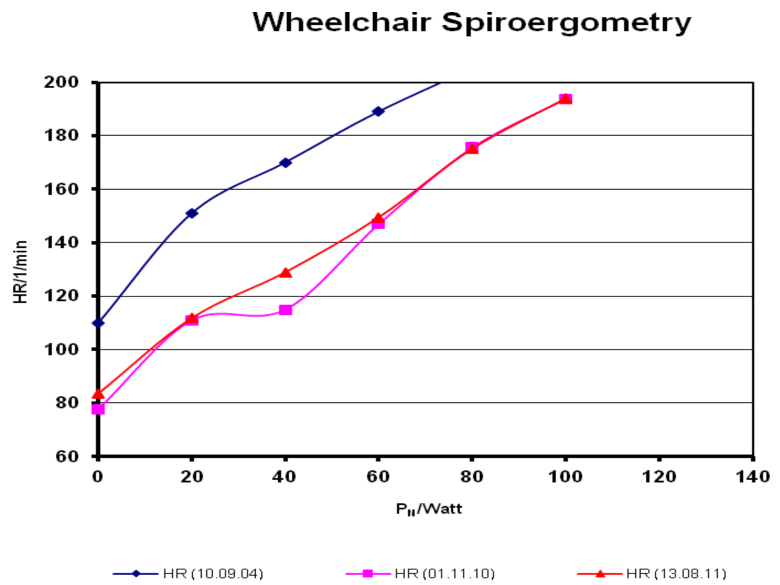



**Figure 2:** HR performance curves in relation to stage of testing, conducted in 2004, 2010 and 2011.

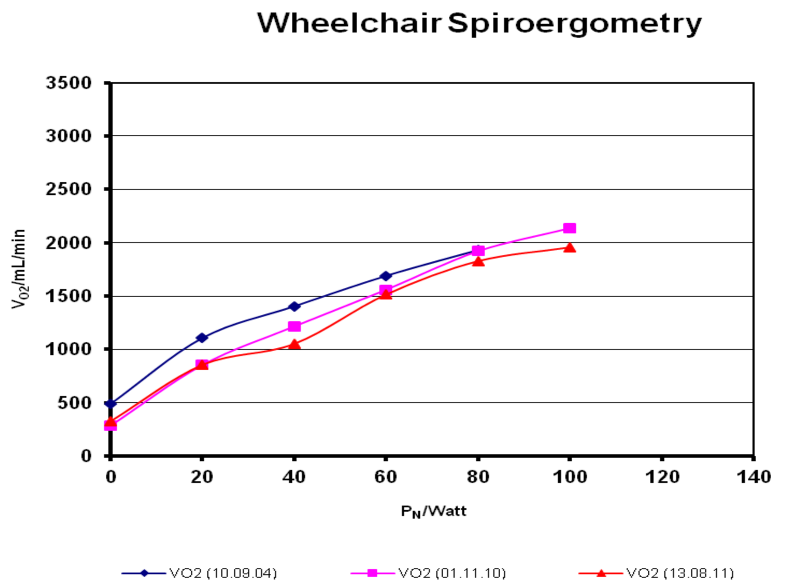



**Figure 3:** $\dot{V}O_2$ performance curves in relation to stage of testing, conducted in 2004, 2010 and 2011.

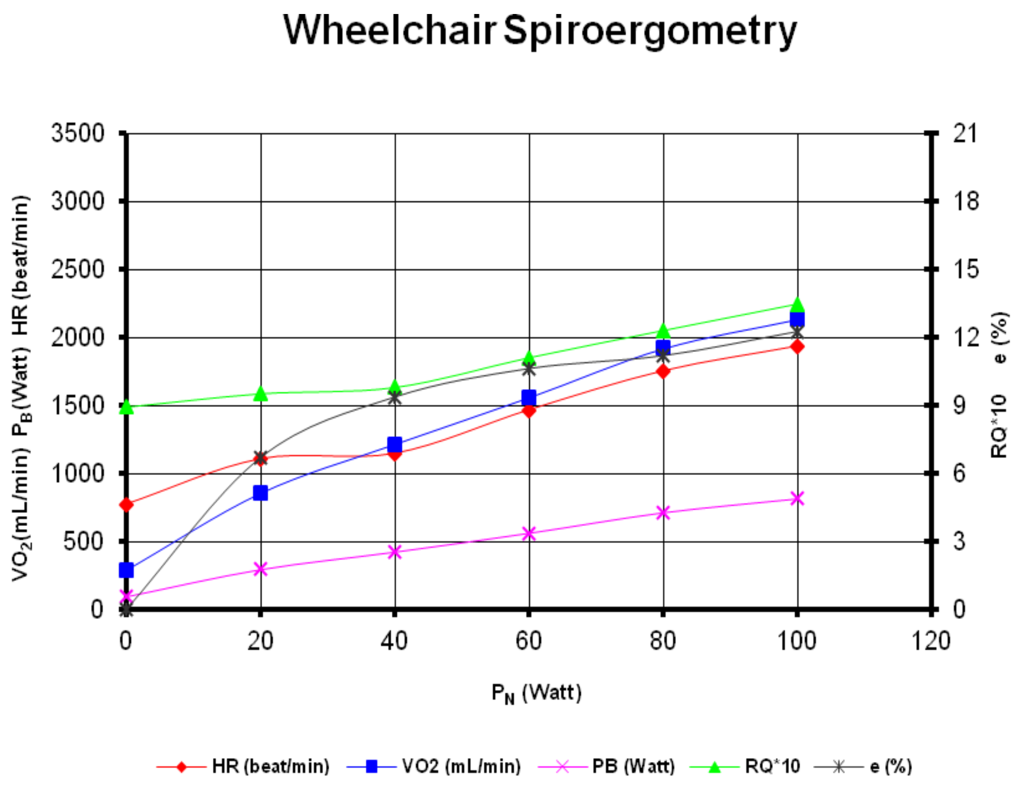



**Figure 4 –** Physiological data recorded during Test 1 in 2010.
Performance curves for HR, $\dot{V}O_2$, $P_B$, RQ and "e", respectively.

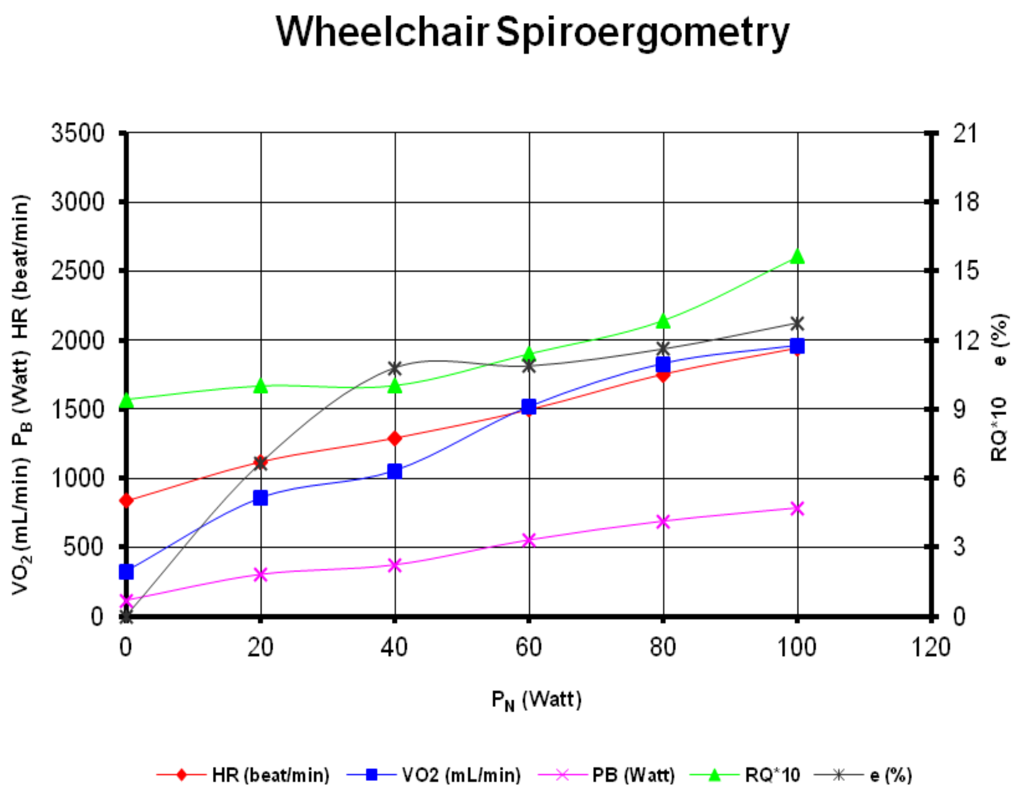



**Figure 5 –** Physiological data recorded during Test 4 conducted in 2011.
Performance curves for HR, $\dot{V}O_2$, $P_B$, RQ and "e" respectively.

Athlete C1 was able to carry out testing for both the campaigns in accordance with the characteristics of the test (progressive loading) and the outlined protocol. From a biomechanical outlook, he was able to maintain regular arm propulsion as the test stages advanced, presenting long "strides" and maintaining a near constant rate per minute, varying the frequency of his arm propulsion from the 1st to the 4th stage from 65-70 strokes/min. The highest load achieved by the athlete during the 5th stage of the first experimental session was 100W (Mechanical Performance - $P_N$), or 816.19W (Physiological Performance – $P_B$), which represented an efficiency (relation to $P_{N/}$ $P_B$) of 12.25%. The highest load achieved by the athlete during the 5th stage of the second experimental session was also 100W ($P_N$), or 784.42W ($P_B$), which represented an efficiency of 12.75%. He presented a $\dot{V}O_2$ of 2137mL/min (34.46mL.min$^{-1}$.kg$^{-1}$) and a lactate level of 10.1mmol/L for the first campaign, and a $\dot{V}O_2$ of 1958mL/min (32.90mL.min$^{-1}$.kg$^{-1}$) and lactate of 9.6mmol/L for the second. Both tests were followed by a 2 times lactate reading as showed in figure 6. The maximum heart rate recorded for the first test was 198bpm, whilst this figure stood at 194bpm for the second campaign. All these measurements were taken immediately after each test came to an end and are shown in Tables 1 and 2.

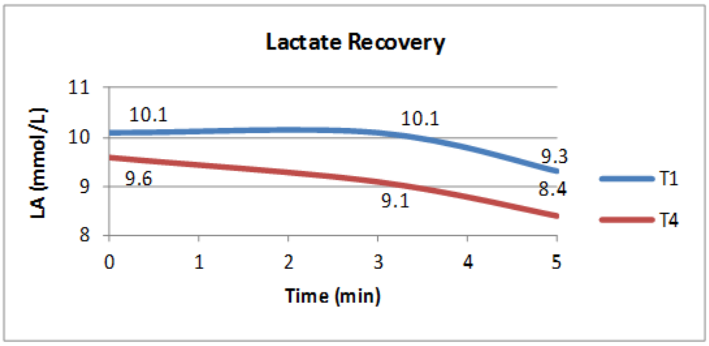



**Figure 6 –** Physiological data (lactate) after Test 1 and Test 4 conducted in 2010 and 2011 respectively.

**Aerodynamic Test**

**Preparations; Control; Immediately before, During, After the test; Recovery**

C1 was the first athlete to take part in the WT evaluation session and as such, he remained in the test section for a longer period of time and was exposed to more airflow than the other participants whilst calibration of the equipment to be used for the experiment took place, and all aspects related to the good performance of the evaluation section were verified.

The volunteers were monitored closely during testing in relation to both their personal safety and to their performance of the test positions to be carried out. The support platform for the sit-ski was also checked to ensure that it did not come into contact with the WT floor, and thus interfere with the action of the balance. C1 consistently performed and repeated every position requested of him, showing no signs of fatigue during testing. The consistency of the force values, together with the respective photographic records for the evaluated settings was also ensured. The endpoint for both tests was carried out by the technical team who were responsible for control management of the WT system and for the timing of photographic records for each position performed, as well as the interval between changes of velocity and position.

The athlete was asked about his experience of the nature and intensity of this new method of evaluation after completion of the test, and reported no discomfort or unhappiness with the procedure. Spontaneous comments made by the athlete in the course of T2 were recorded in field notes, while a questionnaire was applied both before and after the evaluation procedure for T3, bringing the session to an end.

**Results of Aerodynamics Tests 2 and 3**

C1 was able to complete the tests for both the WT campaigns in accordance with the outlined protocol, as can be seen in Table 3. In terms of coordination, he was also able to accurately perform, maintain and repeat the requested positions. The biggest drag force (**D**) presented by him for each of the two tests was 200.83N for T2 and 189.13N for T3, both whilst adopting P1 at 30 m/s. His lowest **D** value for T2 was 14.25N whilst in P4 at 10m/s, and in T3 the lowest value found was 14.27N whilst in P3 at 10m/s. The biggest drag coefficient (**$C_D$**) presented by him in T2 was 0.748 (0.374) whilst adopting P1 at 30m/s, and for T3 this value was 0.360 using the same position. His lowest **$C_D$** value for T2 was 0.496 (0.248) whilst in P4 at both 10 and 20m/s, and for T3 the lowest **$C_D$** value was 0.254 in P3 at 10m/s.

**Table 3 – Wind Tunnel Test Data for C1**

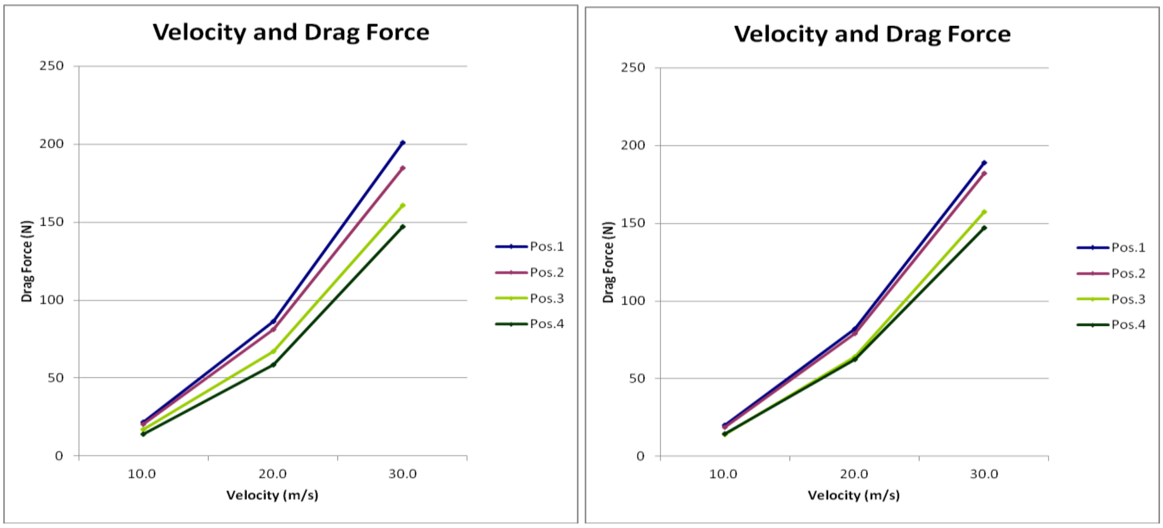
| Pos. | Velocity [m/s] | $C_D$ [-] | $C_D$ [-] | Area [m$^2$] | $C_D$ v2 [-] | D Area [m$^2$] | Drag Force [N] | Drag Force [N] |
|---|---|---|---|---|---|---|---|---|
| Ref. | | 2010 | 2011 | 2011 | 2011 | 2011 | 2010 | 2011 |
| 1 | 10.0 | (0.729) 0.364 | 0.353 | 1.2316 | 0.2869 | 0.434 | 21.70 | 19.94 |
| | 20.0 | (0.721) 0.360 | 0.355 | 1.2316 | 0.2883 | 0.437 | 86.13 | 81.90 |
| | 30.0 | **(0.748)** 0.374 | **0.360** | 1.2316 | 0.2926 | 0. 443 | **200.83** | **189.13** |
| Ref. | | | | | | | | |
| 2 | 10.0 | (0.687) 0.343 | 0.334 | 1.2145 | 0.2751 | 0.405 | 20.36 | 18.82 |
| | 20.0 | (0.682) 0.341 | 0.343 | 1.2145 | 0.2824 | 0.416 | 81.22 | 79.00 |
| | 30.0 | (0.689) 0.344 | 0.347 | 1.2145 | 0.2858 | 0.421 | 184.48 | 182.01 |
| Ref. | | | | | | | | |
| 3 | 10.0 | (0.571) 0.285 | **0.254** | 1.1082 | 0.2289 | 0.281 | 16.90 | **14.27** |
| | 20.0 | (0.566) 0.283 | 0.278 | 1.1082 | 0.2512 | 0.308 | 67.29 | 64.03 |
| | 30.0 | (0.601) 0.300 | 0.300 | 1.1082 | 0.2711 | 0.332 | 160.62 | 157.32 |
| Ref. | | | | | | | | |
| 4 | 10.0 | **(0.496)** 0.248 | 0.260 | | | | **14.25** | 14.63 |
| | 20.0 | (0.497) 0.248 | 0.272 | | | | 58.63 | 62.45 |
| | 30.0 | (0.553) 0.276 | 0.286 | | | | 147.17 | 149.69 |

Obs.: The values were obtained from the estimated frontal area of 0.5 m$^2$ of the athlete in 2010 and 1 m$^2$ in the 2011 test. The numbers highlighted in bold are the maximum and minimum values found in each session. The colours green and orange represent an improvement or deterioration in performance, respectively. The blue represents the values found for the CD from experiment 3 for the new values calculated of the frontal area based on the technique of counting pixels of digital photographs.

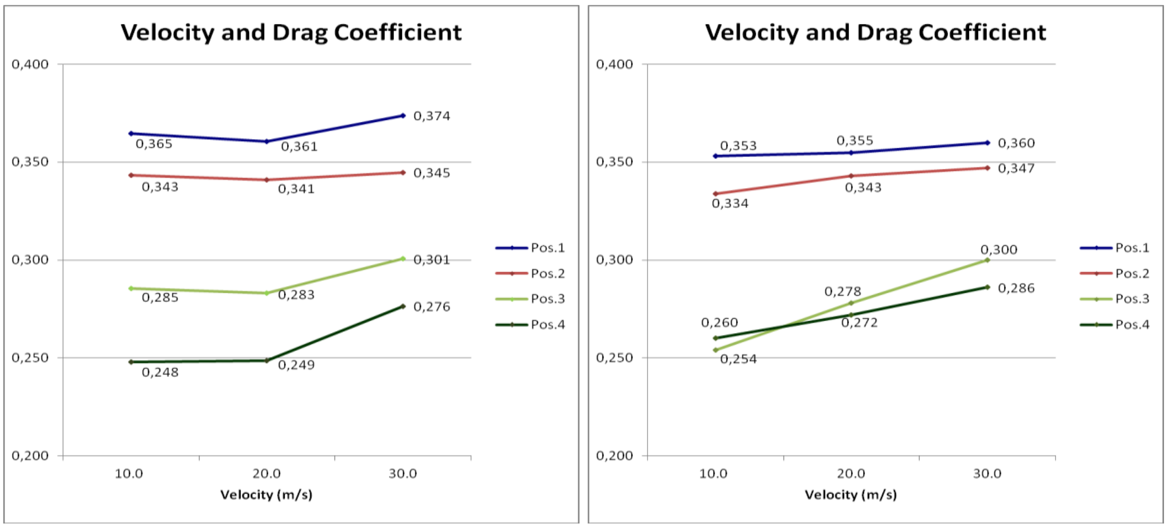
It can be seen from the photographic records that follow that the values presented with respect to each photo have already been corrected so that a direct comparison can be made. Similarly, these values were also used in the construction of comparative graphs between each campaign and configuration performed.

The sports equipment used by C1 was the same for both the campaigns (sit-ski, helmet, goggles, ski wear, ski outriggers and gloves), with the only difference being that he used his jacket to also cover the back part of the seat of the sit-ski for T3, this being the biggest difference between the two tests conducted by him. More detailed descriptions of the positions assumed for the experiments, together with the recorded photos, can be found after the following graphs.

Figures 7 and 8 show the relationship between wind speed and drag force, while figures 9 and 10 present the relationship between wind speed and the drag coefficient generated by the individual.




Figures 7 and 8 – Performance curves for **D** according to test stages performed in 2010 and 2011.




Figures 9 and 10 – Performance curves for $\mathbf{C_D}$ according to test stages performed in 2010 and 2011.

**Description of Positions**

**Lateral photos recorded during the WT experiments**

*P1 - 10 m/s* – For the first position (neutral) in the T2 (photo T2P1S1), the athlete positions himself with his body trunk perpendicular to the ground. His arms are held alongside the body with elbows bent (approx. 70°) and positioned next to the trunk, with his hands holding the ski outriggers diagonally in relation to the ground and avoiding contact with it. In the T3 (T3P1S1 photo), it can be seen that the athlete maintains the same trunk position as previously, but has his arms held slightly further back and with elbows bent (approx. 80º), causing the ski-tip to be more parallel to the ground.

*P1 – 20 m/s* – In the T2 (photo T2P1S2), the athlete reproduced a position almost equal to that assumed at 10 m/s for the principal points of reference (head, arms, trunk, forearms and hands). In the T3 (photo T3P1S2), a slight forward flexion of the neck and retraction of the arms can be seen, allowing the elevation of the skis from the ground.

*P1 – 30 m/s* – In the T2 (photo T2P1S3), the athlete maintains his performance as before, however, the position of the ski-tip changes, increasing the frontal area of exposure. In the T3 (photo T3P1S3), the athlete maintains his performance  as with 20 m/s, however, a slight advance of the arms can be seen as compared to the two previous performances.

**Figure 11: Position 1 – Neutral Position**


photo T2P1S1 – Drag Coeff. 0.364 **10 m/s** photo T3P1S1 – Drag Coeff. 0.353


photo T2P1S2 – Drag Coeff. 0.360 **20 m**/s photo T3P1S 2– Drag Coeff. 0.355

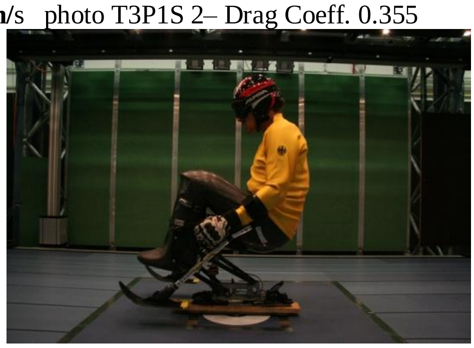



photo T2P1S3 – Drag Coeff. 0.374 **30 m/s** photo T3P1S3 – Drag Coeff. 0.360

*P2 – 10 m/s* – For the second position (run) in the T2 (photo T2P2S1), the athlete assumed a slight forward flexion of the trunk (aprox. 30º). Arms were placed more to the front of the trunk, with elbows positioned close to the body at the height of the thighs and having a lesser degree of flexion (approx. 50º) than for P1. His forearms were slightly more advanced bringing his hands to a position alongside his lower legs. In the T3 (photo T3P2S1), it can be seen that the athlete flexed his trunk and elbows to a greater degree than for the first campaign, the arms slightly indented, the hands together with the legs and the skis more elevated.

*P2 – 20 m/s* – In the T2 (photo T2P2S2), the athlete reproduced a position almost equal to that assumed at 10 m/s moving the arms slightly forward and further extending the elbows, allowing the hands to advance even more. In the T3 (photo T3P2S2), the athlete again reproduced the position practically equal to that assumed at 10 m/s, with the trunk and arms held slightly further back.

*P2 – 30 m/s* – In the T2 (photo T2P2S3), the athlete reproduced a position almost equal to that assumed at 20 m/s but with greater forward flexion of the neck. In T3 (photo T3P2S3), the athlete maintained his performance as with 20 m/s, however, the trunk can be seen to be positioned slightly further back.

**Figure 12: Position 2 – Run Position**

photo T2P2S1– Drag Coeff. 0.343 **10 m/s** photo T3P2S1– Drag Coeff. 0.334

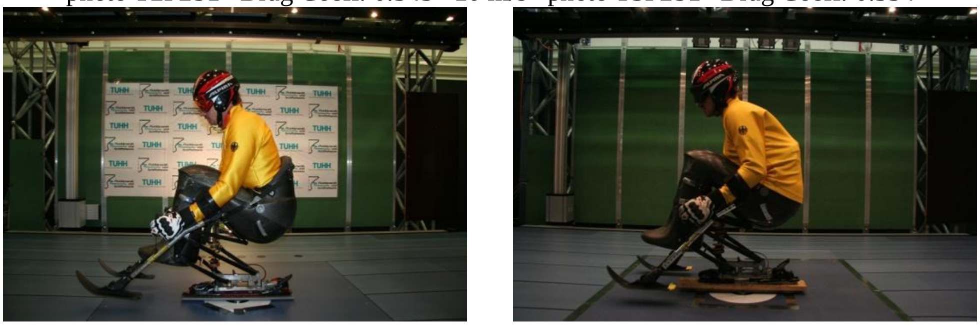


photo T2P2S2 – Drag Coeff. 0.341 **20 m/s** photo T3P2S2 – Drag Coeff. 0.343

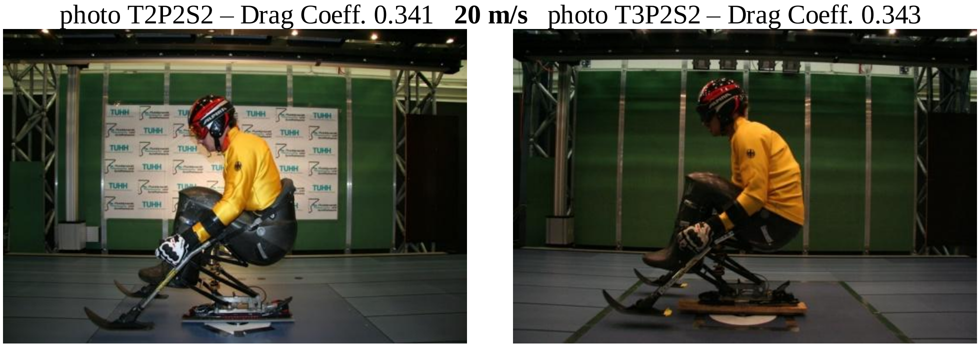


photo T2P2S3 – Drag Coeff. 0.344 **30 m/s** photo T3P2S3 – Drag Coeff. 0.347

*P3 – 10 m/s* – For the third position (aggressive) in the T2 (photo T2P3S1), the athlete adopted a position of maximum forward flexion of the trunk (approx. 45º) with arms at near right angles to the body. Elbows were almost fully extended and positioned close to the body at the height of the legs. His forearms were further forward with the hands positioned well in front in relation to the line of the legs. In the T3 (photo T3P3S1), it can be seen that the athlete assumed a maximum forward flexion of the trunk with elbows bent (approx. 50º). The arms were held slightly further back with the hands positioned just in front of the legs.

*P3 – 20 m/s* – In the T2 (photo T2P3S2), the athlete reproduced a position almost equal to that assumed at 10 m/s but with a subtle difference in head position leaving his face pointing more towards the ground. In the T3 (photo T3P3S2), the athlete reproduced a position almost equal to that assumed at 10 m/s for the principal points of reference (arms, trunk, forearms and hands), just raising his head a little.

*P3 – 30 m/s* – In the T2 (photo T2P3S3), the athlete reproduced the position almost equal to that assumed at 10 m/s but with the elbows more bent. In the T3 (photo T3P3S3), the athlete maintained his performance as at 20 m/s, however, with the arms held slightly further back and the elbows a little more bent.

**Figure 13: Position 3 – "Aggressive" Position**

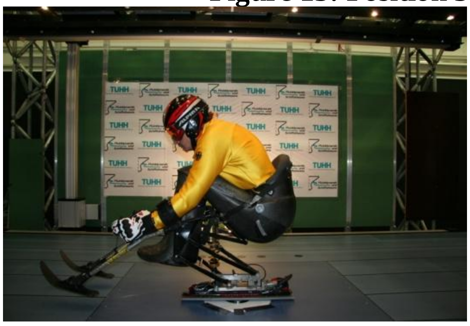



photo T2P3S1 – Drag Coeff. 0.385 **10 m/s** photo T3P3S1 – Drag Coeff. 0.254

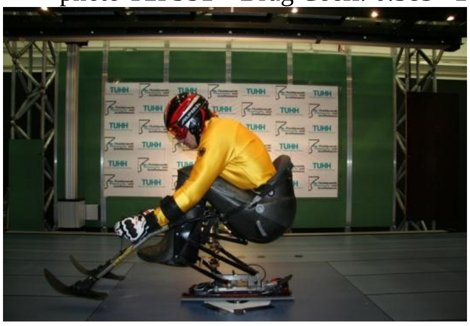



photo T2P3S2 – Drag Coeff. 0.383 **20 m/s** photo T3P3S2 – Drag Coeff. 0.278

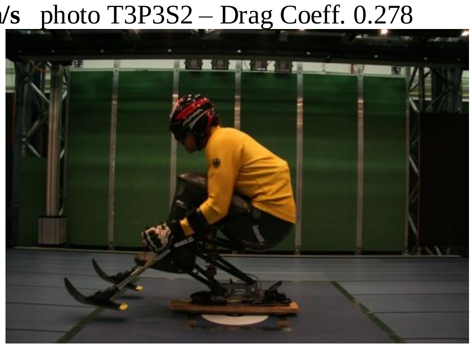



photo T2P3S3 – Drag Coeff. 0.300 **30 m/s** photo T3P3S3 – Drag Coeff. 0.300

*P4 – 10 m/s* – The fourth position (extra) is derived from P3. In the T2 (photo T2P4S1), the athlete assumed maximum forward flexion of the trunk (approx. 45º). The main difference seen was in the differing positions of the arms, with the left arm held as with position 3 but the right arm having greater elbow flexion (approx. 90º), thus raising the ski-pole to a position above the line of the horizon (positive angle of attack). In the T3 (photo T3P4S1), the athlete had maximum forward flexion of the trunk with the upper left arm perpendicular and the forearm oblique to the ground, maintaining the ski-pole at that same angle. As in the 1st campaign, the right elbow was bent (approx. 90º), raising the ski-pole to a position above the line of the horizon.

*P4 – 20 m/s* – In theT2 (photo T2P4S2), the athlete reproduced a position almost equal to that assumed at 10 m/s but lowering the head and bringing the chin a little closer to the knees. In the T3 (photo T3P4S2), the athlete reproduced a position almost equal to that assumed at 10 m/s for the principal points of reference (head, arms, trunk, forearms and hands), but slightly lowering his shoulders.

*P4 – 30 m/s* – In the T2 (photo T2P4S3), the athlete reproduced a position almost equal to that assumed at 20 m/s. In the T3 (photo T3P4S3), the athlete maintained his performance as at 20 m/s.

**Figure 14: Position 4 – Extra Position**

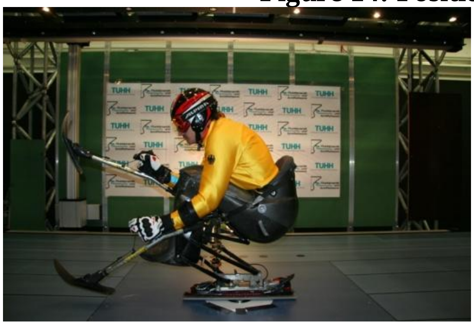



photo T2P4S1 – Drag Coeff. 0.248 **10 m/s** photo T3P4S1 – Drag Coeff. 0.260


photo T2P4S2 – Drag Coeff. 0.248 **20 m/s** photo T3P4S2 – Drag Coeff. 0.272

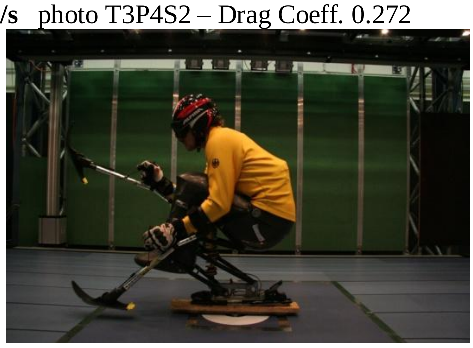



photo T2P4S3 – Drag Coeff. 0.276 **30 m/s** photo T3P4S3 – Drag Coeff. 0.286

**Frontal Photos Recorded after WT Experiments**

*P1 – No wind* – It can be seen from the photo (T2P1) in the T2 that the athlete's head was leaning slightly to the left but with shoulders level. His arms were held alongside his body and positioned close to the trunk. Elbows and hands were kept level whilst holding the *ski poles* and preventing the ski-tips from coming into contact with the ground. The trunk was aligned with the monoski. In the T3 (photo T3P1), it was possible from the photo taken to calculate the area of the athlete complete with the monoski, generating from this the diagram for the calculation of area (T3P1v2).

**Figure 15: Position 1 – Neutral Position**

photo T2P1 photo T3P1 T3P1v2

*P2 – No wind* – It can be seen from the photo (T2P2) in the T2 that the athlete's head was leaning slightly to the right but with shoulders level. His arms were held alongside his body and positioned close to the trunk. Elbows and hands were kept level whilst holding the ski poles and preventing the ski-tips from coming into contact with the ground. The trunk was aligned with the monoski. In T3 (photo T3P2), it can be seen that the athlete reproduced the same posture as in the first campaign. From the photo taken it was possible to produce the diagram (T3P2v2) and calculate the area of the athlete complete with the monoski in P2.

**Figure 16: Position 2 – Run Position**

photo T2P2 photo T3P2 T3P2v2

*P3 – No wind* – It can be seen from the photo (T2P3) in the T2 that the athlete's head was in alignment with the monoski with his shoulders level. His arms were positioned alongside his legs and held close to them. Elbows and hands were kept level whilst holding the ski poles and maintaining the ski-tips raised from the ground. The trunk was aligned with the monoski. In the T3 (photo T3P3), little difference was perceived in the execution of the position. The arms were held close to the legs and the trunk slightly misaligned with the structure of the monoski. From the photo taken it was possible to produce the diagram (T3P3v2) and calculate the area of the athlete complete with monoski in P3.

**Figure 17: Position 3 – "Agressive" Position**

photo T2P3 photo T3P3 T3P3v2

*P4 – No wind* – A photo was taken for the T2 only (photo T2P4) and showed that the athlete's head was aligned with the monoski and his shoulders kept level. His arms were held in different positions with the left being lower and kept close to his legs, whilst the right arm is held close to the body but with elbow bent and the hand positioned close to the knee, maintaining the ski-tip in front of the body.

**Figure 18: Position 4 – Extra Position**

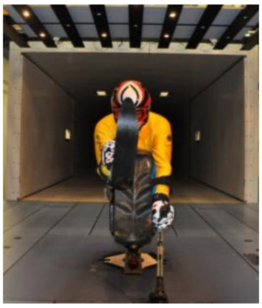


photo T2P4

The general results of the anthropometric evaluation, the treatment of the photographic records, and the questionnaires and field notes completed by the athlete and trainer for both campaigns have now been presented. We would now like to put forward, in addition to the individual results presented in relation to tests performed on the ergometric treadmill, and in the wind tunnel, a follow-up of the individual analysis by means of a discussion for the athlete in question.

### 2.1.2 Human Performance - Discussion

**Objectives Assessment**

The evaluation process was conducted with the intention of increasing the range of information and understanding of the performance structure that affects the world of the athletes from the *DPS* team. It also aimed to analyse and compare individual results, contrasting them with other team members and to eventually relate these to other Paralympic athletes (e.g. wheelchair sports).

This athlete, born in June 1984, has a training history of nearly 10 years with the *DPS* team. He participated in the Winter Paralympic Games in Vancouver, performing well but did not win any medals. He was exemplary in his performance of the experiments developed over the two evaluative campaigns of this study and presented interesting and respectable results for this competitive sport, as well as for the scientific community.

**Anthropometric Assessment**

From the anthropometric measurements taken, it was observed that the volunteer reduced his body weight from 62kg to 59.5kg during the period between the two evaluative campaigns. As a consequence, this altered his body mass index with it reducing to 23.24kg/m$^2$, however, remaining within the range considered as normal according to "The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults" (National Institutes of Health, 2000).

Data collected during the 2$^{nd}$ campaign included measurement and recording of the seated height (116cm) and arm-span (177.5cm) of C1. From this information it was possible to determine his trunk index (Cormic Index, the ratio between the seated height and total height; Relative Arm-span, arm-span in relation to height). C1 presented the highest Cormic Index (72.5) of all those athletes taking part in the 2nd campaign, and it can be said that C1 has an advantageous trunk height and larger relative arm-span (110.93) in terms of his total height. In relation to the sport of Alpine Skiing, this presents a disadvantage from an aerodynamics perspective given that his frontal area is subject to wind exposure whilst skiing, and an advantage from a motor point of view as his arms have greater reach, thus affecting his directional ability and maintenance of equilibrium.

**Physiological Assessment**

These anthropometric characteristics can be considered advantageous for pre-season fitness preparations in terms of physiology. Having a larger trunk size and relative arm-span can enable an athlete to increase the muscle mass of the trunk and upper limbs and improve aerobic fitness, having a positive effect on metabolism and reducing complications caused by the spinal cord injury (Bhambhani, 2003). The spiroergometry evaluation carried out to check the fitness condition of this athlete produced consistent and coherent results without exposing him to risk. This present study was also able to take into account and to use as a benchmark for comparison of performance evolution, previous results presented by C1 in 2004. It can be said that C1 has reached a plateau, having presented very similar performances in 2010 and 2011, with testing on both occasions ending at the same stage and within the same time duration, and in addition presenting virtually the same $HR_{max}$. When comparing the $\dot{V}O_2$ readings of C1, they were lower in the 2011 evaluation when compared to both 2004 and 2010, although, he was able to continue the test for a longer time period in 2010 and 2011. The $\dot{V}O_2$ values presented by C1 were 2137ml/min (34.46 ml/kg/min) in the 1st campaign and 1958ml/min (32.90 ml/kg/min) in the 2nd campaign. Although this test protocol differs from those adopted by other authors in their evaluations, as detailed by (Bhambhani, 2002) in Table 4, the results are comparable with them. It should be noted that the results encountered in Table 4 refer to trained and untrained individuals in wheelchair sports.

**Table 4 – Peak Aerobic Power in Trained and Untrained Male Wheelchair Athletes with Paraplegia**

| Study | Mode | n | ISMGF classification | Lesion | $VO_2$ (L/min) | $VO_2$ (ml/kg/min) | HR (beats/min) |
|---|---|---|---|---|---|---|---|
| **Trained** | | | | | | | |
| Bernard et al. | WERG | 6 WA | IV | T11-L3 | 1.79 | 28.5 | 183 |
| Campbell et al. | WCT | 10 WA | | T2-L2 | 1.91 | | 196 |
| Huonker et al. | WERG | 29 WA | II-V | T1-S2 | 2.42 | 34.5 | 183.3 |
| Price Campbell | ACE | 11 WA | | T3-4-L1 | 2.04 | 30.5 | 185 |
| Van der Woude et al. | WERG | 8 WA | | T3-L1 | 2.04 | 32.9 | |
| | WERG | 23 WA | | T6-S1 polio, spina bifida | 2.29 | 38.1 | |
| Veeger et al. | WCT | 13 WA | IV | T11-L3 | 2.42 | 36.9 | 182 |
| Vinet et al. | WCT | 8 WA | III-V | T8-L5 | 2.67 | 40.6 | 174 |
| **Untrained** | | | | | | | |
| Janssen et al. | WCT | 12 UT | IV | | 2.03 | 25.7 | |
| Huonker et al. | WERG | 20 UT | II-V | T1-S2 | 1.76 | 23.9 | 161.8 |

ACE – arm crank ergometer; i – incomplete lesion; ISMGF International Stoke Mandeville Games Federation functional classification; n – sample size; $VO_2$ - Oxygen Uptake; UT – untrained participants; WA – wheelchair athletes (mixed group of athletes); WCT – wheelchair mounted on treadmill; WERG – wheelchair ergometer. Table incomplete, taken from an article by Yagesh Bhambhani (2002).

In assessing the functional capacity of C1, we must look at the mechanical and physiological performance and the relationship between them (Wüpper, 2002). Athlete C1 was able to advance to the 5$^{th}$ stage (100W) for both campaigns and continue there for 1min 30s in experiment n.1 and 1min 36s in experiment n.4. From a physiological perspective he was able to generate 816.19W, representing an efficiency of 12.25% for T1, whilst in T4 he was able to generate 784.42W, representing a slightly better efficiency of 12.75%. Comparing these results with those obtained from athlete C6 who completed his test using a bicycle ergometer, it indicates that the upper limbs are less efficient than the lower limbs.

When comparing the HR reached with the maximum pre-determined HR according to the Karvonen formula (Robergs 2002, Policarpo 2004), the peak HR reached by volunteer in the two evaluative campaigns was equivalent to the pre-determined $HR_{max}$. Follow-up measurements for C1 taken 3 minutes after both tests were ended showed his HR to be below 140bpm (113bpm and 111bpm, respectively), indicating good cardiovascular conditioning given the manner in which he was able to recover. Table 4 verifies the results presented in these experiments, although the ages of those volunteers performing the tests is not included.

No fluctuation in lactate concentrations was found in respect of lactate values encountered during testing with C1, with direct readings being taken during the post-test recuperation period for both campaigns. It can be argued that the volunteer's response in the 2$^{nd}$ campaign was better, noting that it took place in a transition period between vacations and the beginning of pre-season competitive training.

**Aerodynamic Evaluation**

The aerodynamics evaluation was intended to take account of the amount of drag produced by the athletes and generated innovative results without exposing C1 to risk. The performance of C1 over the two campaigns was very similar but he was still able to improve his results in the 2011 evaluation, conducting his test within the set parameters and recording lower values in almost all the positions carried out. As can be seen in Table 3 and in Figures 7, 8, 9 and 10, the values obtained in the test were quite consistent (Vinagre *et al*, 2012).

In a comparison of the results for the **D** values in 2011 with those of 2010, it can be seen that C1 was able to reduce the **D** value generated by the posture P1, which creates the most resistance. Additionally, deterioration in the performance of P4 in 2011 can be seen, in relation to 2010. In the other previously performed positions, C1 was able to produce an improved performance for them all in 2011 in comparison to 2010, as can be seen in Table 3 and Figures 7 and 8.

However, when comparing the $\mathbf{C_D}$ values between the two years, a greater consistency in results was seen in 2011, reflected in there being an increase in $\mathbf{C_D}$ for all position performed following an increase in wind velocity. This was not the case in experiment n.2 in 2010 for positions P1, P2 and P3 when a decrease in $\mathbf{C_D}$ was seen when passing to the second stage (20m/s). Incorporating calculation of the $\mathbf{C_D}$ according to the frontal area of the individual in the 2$^{nd}$ campaign in 2011 brought with it even more accurate values and refined data than was the case in 2010, or in other experiments from the 1970's (Bendig, 1975) conducted with the German Olympic alpine skiing team. The values of the **D Area** for C1 calculated from the frontal area at 30m/s represent 0.443$m^2$ in P1, 0.421$m^2$ in P2 and 0.332$m^2$ in P3.

**Postural Evaluation**

**Analysis of Lateral Photos**

An analysis of the posture of C1 for both campaigns was conducted. A slight variation should be noted in that during testing for T3, C1 altered the manner in which his jacket was worn from the previous WT test, with the bottom now being pulled over the top of the sit-ski. In P1, both in 2010 and 2011, the volunteer was able to carry out and repeat the posture with only small changes in trunk position. Comparing the postures adopted in this campaign with the previous, a fundamental change in head position can be seen (in 2011, C1 holds his head lower and more to the front) and in arm position (in 2011 they are positioned further back in relation to the longitudinal axis of his body).

In P2, it can be seen that in 2010 C1 showed consistency in his performance, however in 2011 we can note that his trunk posture showed more variation. When comparing postures between the two campaigns, we can see that in 2011 C1 displayed greater trunk and elbow flexion.

In P3, both in 2010 and 2011, C1 showed a consistency in performance, indicating that this position is one that is easier to maintain and is well suited in terms of execution of the position. Comparing the postures from both campaigns, it can be seen that in 2010 C1 assumed a position having a more rounded back, whilst in 2011 he maintained a straighter back with greater flexion of the elbows.

In P4, it can be seen that in both 2010 and 2011, despite the differing positions of holding the ski outriggers, C1 could carry out and maintain the position easily, especially when compared to P2. When comparing the postures from one campaign to the other, it was in P4 that C1 was able to perform in the most similar way over the course of both tests.

**Analysis of frontal photos**

An analysis of the postures held by C1 in the frontal plane for the two campaigns demonstrates that for both 2010 and 2011, the volunteer was able to carry out and repeat the posture for P1 with minimal alterations in head, trunk and ski outrigger position, with this also being the case for P2. In P3 a small difference was seen in the positioning of the ski outriggers with them being held further from the central axis. It is interesting to compare the additional diagrams created only in 2011 from the T3 photos for positions P1, P2 and P3, which give a clearer representation of the frontal area generated by the different postures assumed by C1.

**Questionnaires**

Questionnaires applied in the 2$^{nd}$ campaign only, provided more important information regarding the perception of discomfort through use of the Body Discomfort Diagram (BDD). C1 noted experiencing some discomfort in the thoracic region, moderate/high level of discomfort in the lumbar region, and moderate/high to unbearable discomfort for the hips and lower limbs. Exact details of the beginning of his training season (June) were obtained and of the overall progress of his training year. C1 trains on a daily basis during 3/4 of the year (June to March), and on some days carries out two different forms of training sessions. In the period from March to June after the competitive season has ended, the training schedule reduces with C1 completing only 2-3 workouts per week, with the emphasis being on aerobic endurance. In the months from Sept/Oct. to December, the training developed to date is maintained, reducing the weekly frequency and increasing the technical work element to 3 times a week. It is the technical training that consumes the greatest amount of the athlete's time and can extend up to 4 hours in duration. The competition season takes place in the months from Dec/January until March, and C1 tries to divide his training schedule so that 50% of his time is dedicated to physical workouts and the remaining 50% to technical and tactical training.

His best results achieved in the world of Alpine Skiing (World Championship Sestriere/ Italy), took place between the two evaluative campaigns when he finished in 3$^{rd}$ place in the Slalom race. This is an activity that demands a greater degree of manoeuvrability than required for Downhill racing (speed), in which he finished in 7$^{th}$ place. It is important to point out that the season ended without him having suffered any accident or significant injury.

Contrary to what was noted on the BDD, C1 indicated in the questionnaire that he feels comfortable in his wheelchair and that he is not generally in pain. In the replies related to the WT evaluation, it can be seen that C1 was able to safely and comfortably conduct the test although he found its demands relatively difficult. He believes the test results to be important but does not know exactly how they can be incorporated into his performance and training routine. His completion of the post-test questionnaire confirmed what he had stated in the pre-test questionnaire, but added to the information that he feels the most enjoyable test position he performs to be P3.

From responses related to the test conducted at the Physiology Laboratory, it can be seen that C1 was able to safely perform the test but did not feel as comfortable, principally from a respiratory point of view and in particular, in the position requiring the trunk to be bent forward. Although he found the level of demand for the test relatively difficult, he was able to continue for as long as possible. He believes these test results to be more important than those found in the WT, in terms of his performance and training. He also believes that his training has been adapted to take into account a number of improvements from the sessions. In the post-test questionnaire, C1 confirmed his statements made pre-test, that he believes he is in a period of very good physical fitness.

**2.2 Case number 2/ Volunteer (C2)**

The second case is an athlete from the female alpine ski team, born on 26/01/93, and having a disability classification of LW10-2 in the sitting skiers (monoskiers) category. She has complete paraplegia, presenting with spinal muscular atrophy (T5 level/ Thoracic spinal stenosis) since 3 years of age (Haupts, 1987). This deficiency is considered moderate/severe, given that it is a degenerative change preventing movement of her legs and part of the body trunk. Her first monoski course was in October 2007. She took part in the Euro Cup as a member of the *DPS* team in 2008/9 and in the World Cup in 2009/10. She has obtained satisfactory results in the sport and her performance has improved with each passing year.

As can be seen from Table I and II (p.78), C2 is 150cm tall and weighed 43kg at her last evaluation, giving a Body Mass Index of 19.11 $kg/m^2$. Measurements of her seated height and arm-span were also taken during the latter evaluative campaign, which allowed her Cormic Index and relative arm-span to be determined. The individual assessment of C2 also enabled other important information to be obtained, such as for example, that she suffered a concussion during the 2010 World Championship.

**2.2.1 Tests**

C2 was the second participant to complete the ergometric treadmill test in both the first and second campaigns. She was the seventh athlete to take part in the first aerodynamics wind tunnel campaign, but took part in second position for the second campaign. C2 followed the standard protocol in accordance with the pre-planned steps for the treadmill spiroergometry evaluations scheduled for test sessions 1 and 4, although she had never taken part in such a procedure before. She was also unfamiliar with the wind tunnel testing that took place in sessions 2 and 3, and was the first female seated monoski athlete to carry out these tests.

**Cardiopulmonary Test**

**Preparations; Control; Immediately before, During, After the test; Recovery**

The initial load encountered for test number 1 (T1) was 3.94N and for test number 4 (T4) was 4.52N. The blood sample taken prior to T1 showed a lactic acid concentration of 0.8mmol/L, whilst the reading prior to T4 was 0.9mmol/L. The cardiac electrical activity of the volunteer was monitored closely during testing, together with the consistency of the recorded physiological values to ensure that none of the monitored recordings showed any warnings signs. Both of the test sessions were brought to an end at the request of the athlete, having reached her limit of endurance. New blood samples were collected immediately at test end, and again 3min. and 5min. after the end, with these values being presented in Tables 5 and 6. After removal of the mouthpiece/mask, the participant was asked about the nature and intensity of the limiting symptoms, with the replies being recorded on a standard form. Routine post-tests were conducted during the recovery period to ensure that both ECG and systemic blood pressure measurements returned to normal before the release of the volunteer, and the official ending of the test session.

**Results of Cardiopulmonary Tests 1 and 4**

The volunteer was required to pass a pre-test for both evaluative campaigns before being allowed to take part in the actual testing session. The readings for $\dot{V}O_2$, HR and load values obtained from the spiroergometry are listed in Table 5 and 6 and in Figures 19, 20, 21 and 22.

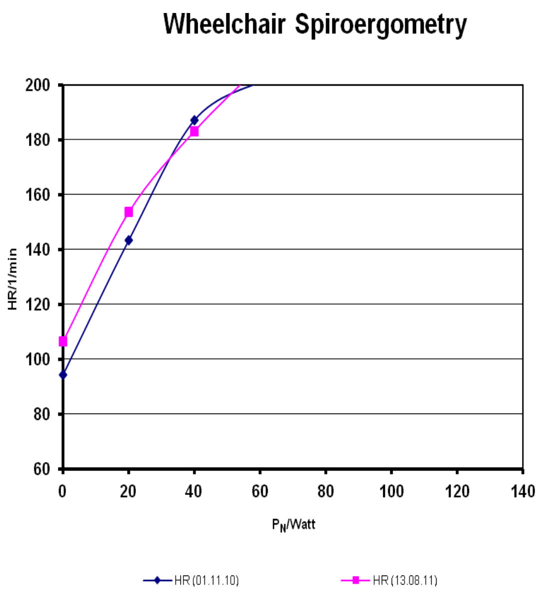
**Tables 5 and 6 – Results of Tests 1 and 4 for Athlete C2**

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 94 | 323 | 0.781 | 107.52 | 0.00 | 0.8 |
| 3 | 20 | 143 | 948 | 0.722 | 311.26 | 6.43 | |
| 3 | 40 | 187 | 1271 | 0.961 | 443.39 | 9.02 | |
| 1min.10s | 60 | 201 | 1607 | 1.169 | 589.37 | 10.18 | |
| | | | | | | | |
| after stop | | 200 | | | | | 7.8 |
| 1 | | 191 | | | | | |
| 2 | | 171 | | | | | |
| 3 | | 153 | | | | | 8.5 |
| 4 | | 147 | | | | | |
| 5 | | 144 | | | | | 7.4 |

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 107 | 287 | 0.900 | 98.50 | 0.00 | 0.9 |
| 3 | 20 | 154 | 1032 | 0.856 | 350.61 | 5.70 | |
| 3 | 40 | 183 | 1350 | 1.022 | 477.90 | 8.37 | |
| 3 | 60 | 207 | 1768 | 1.205 | 653.79 | 9.18 | |
| | | | | | | | |
| after stop | | 205 | | | | | 8.8 |
| 1 | | 183 | | | | | |
| 2 | | 159 | | | | | |
| 3 | | 148 | | | | | 7.3 |
| 4 | | 134 | | | | | |
| 5 | | 143 | | | | | 7.4 |

$P_N$ – Mechanical output, HR - Heart Rate, $VO_2$ - Oxygen Consumption, RQ - Respiratory Quotient, $P_B$ Gross output, e - equivalent $P_N/P_B$, LA – Lactate.

**Figures 19, 20, 21 and 22 – Results of Spiroergometry (tests 1 & 4) for athlete C2**



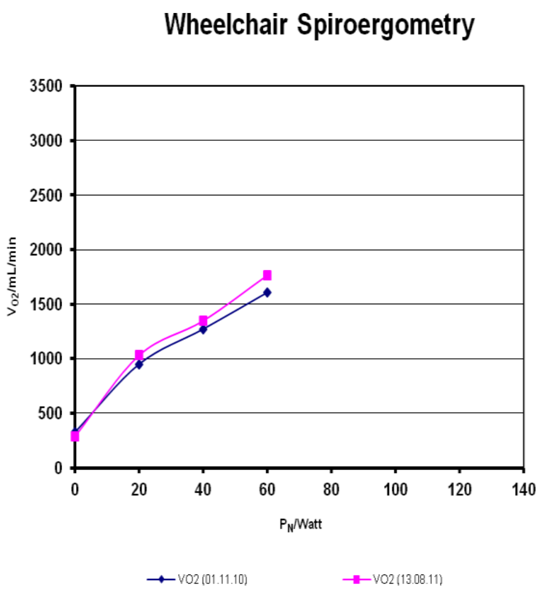




**Figure 19:** HR performance curves in relation to stage of testing, conducted in 2010 and 2011.
**Figure 20:** $\dot{V}O_2$ performance curves in relation to stage of testing, conducted in 2010 and 2011.

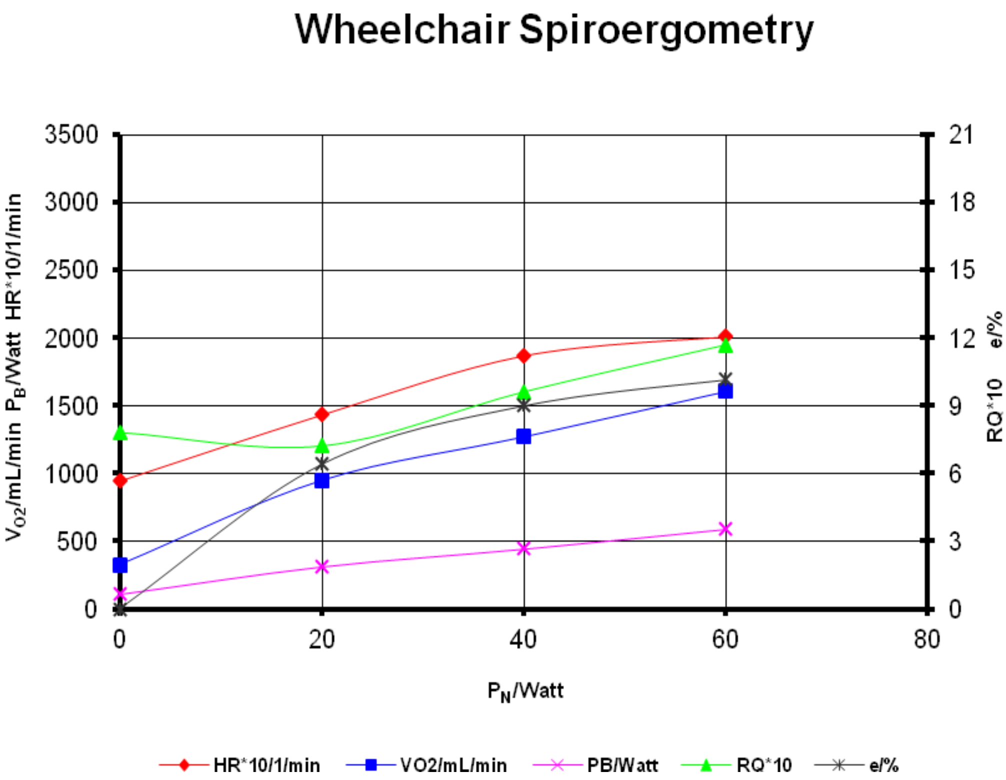



**Figure 21 –** Physiological data recorded during Test 1 in 2010. Performance curves for HR, $\dot{V}O_2$, $P_B$, RQ and "e", respectively.

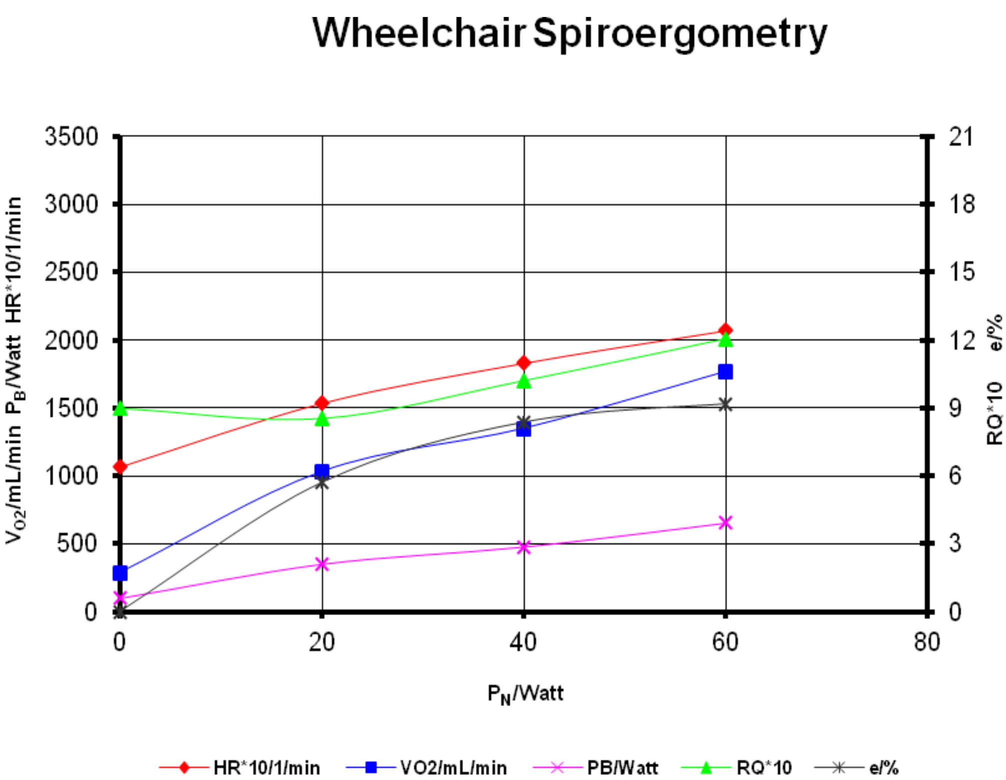



**Figure 22 –** Physiological data recorded during Test 4 conducted in 2011. Performance curves for HR, $\dot{V}O_2$, $P_B$, RQ and "e", respectively.

Athlete C2 encountered some difficulty in maintaining a long duration test performance in the 1st campaign. She advanced until the third stage but was unable to complete the entire time of 3 minutes for this. From a biomechanical outlook, the athlete found it difficult to maintain a good posture, with her trunk tending to bend to the right. The frequency of her arm propulsion varied as the test phases advanced, having an irregular frequency per minute. The highest load achieved by the athlete for both the first and second experimental sessions was 60W, achieved during the 3rd stage. She presented a $\dot{V}O_2$ of 1607ml/min. and a lactate level of 7.8mmol/L immediately after the test end for the 1st campaign, followed by a lactate reading of 8.5mmol/L from her 2nd blood collection after 3 minutes.

In the 2nd campaign, the athlete was able to carry out the test in accordance with the outlined protocol, and although she could not continue to the 4th stage, she was able to complete the 3rd maintaining a more comfortable posture and without excessive leaning to one side or the other. She presented a $\dot{V}O_2$ of 1768ml/min. and a lactate level of 8.8mmol/L immediately after the test end, followed by a lactate reading of 7.3mmol/L from her 2nd blood collection after 3 minutes (Figure 23). The maximum heart rate reached for the 1st test was 201bpm, whilst this figure stood at 207bpm for the 2nd campaign. These measurements were taken immediately after each test came to an end and are shown in Tables 5 and 6.

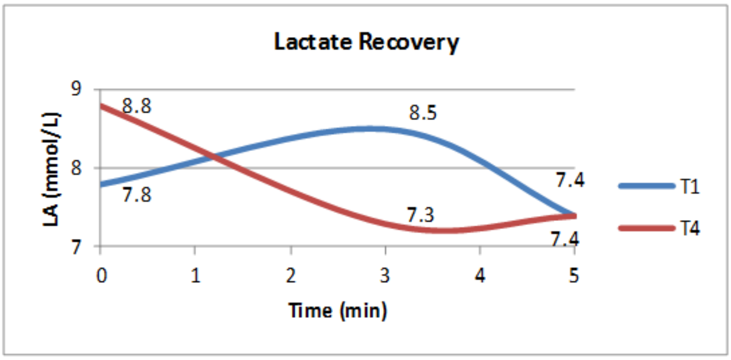



**Figure 23 –** Physiological data (lactate) after Test 1 and Test 4 conducted in 2010 and 2011 respectively.

**Aerodynamics Test**

**Preparations; Control; Immediately before, During, After the test; Recovery**

The volunteer was monitored closely during testing in relation to both her personal safety and her performance of the test positions to be carried out. No contact occurred during testing between the support platform for the monoski and the WT floor. The volunteer experience some difficulty in the execution and maintenance of the requested positions during the 1st campaign, primarily in pos. 4, and showed signs of fatigue with 30 minutes of testing. This was not the case for the 2nd campaign, with athlete C2 being able to perform all the required steps during the WT testing. The consistency of the force values together with the respective photographic records for the evaluated settings, were ensured. The endpoint for both tests was carried out by the technical team who were responsible for control management of the WT system and for the timing of photographic records for each position performed, as well as the interval between changes of velocity and position.

The athlete was asked about her experience of the nature and intensity of the test after completion, and indicated that she had no complaints to report. Spontaneous comments made by the athlete in T2 were recorded in field notes, while a questionnaire was applied both before and after the evaluation procedure for T3.

**Results of Aerodynamics Tests 2 and 3**

C2 was not able to complete all of the planned steps outlined in the protocol for the first campaign, as can be seen in Table 7 and from the photographic records. In terms of coordination, she found it relatively difficult to execute, maintain and repeat the requested positions, but performed them as much as possible. The biggest **D** presented by her for each of the two tests was 202.98N in T2 and 201.44N in T3, both whilst adopting P1 at 30m/s. Her lowest **D** value for T2 was 12.82N whilst in P3 at 10 m/s, and in T3 the lowest value found was 12.86N whilst in P4 at 10 m/s. The biggest $\mathbf{C_D}$ presented by her in T2 was 0.768 (0.384) whilst adopting P1 at 30m/s, and for T3 this value was 0.386 using the same configuration. Her lowest $\mathbf{C_D}$ value for T2 was 0.438 (0.219) in P3 at 10m/s, and for T3 the lowest $\mathbf{C_D}$ value was 0.230 in P4 at 10m/s.

**Table 7 – Wind Tunnel Test Data for C2**

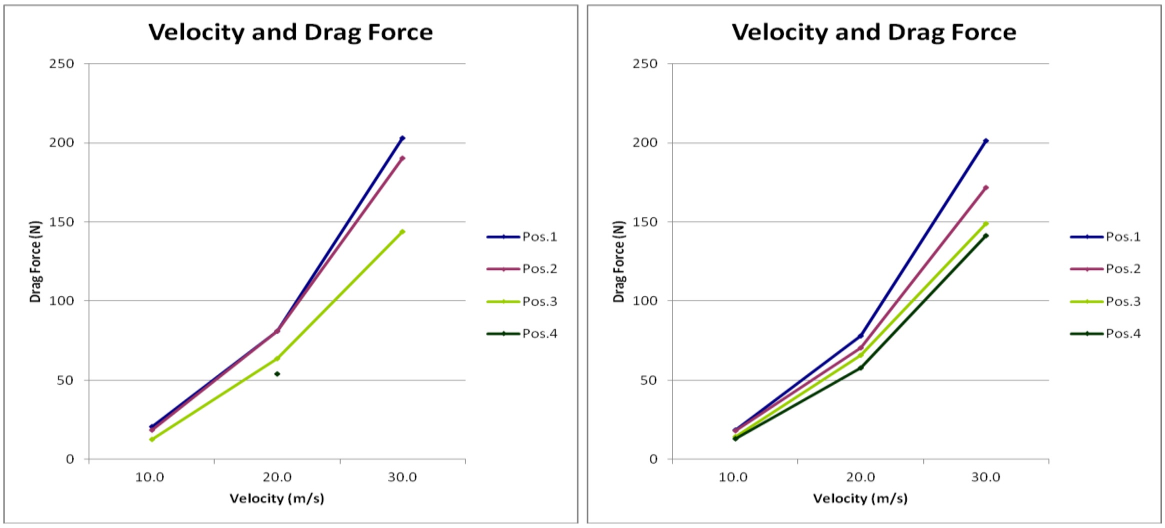
| Pos. | Velocity [m/s] | $C_D$ [-] 2010 | $C_D$ [-] 2011 | Area [m$^2$] 2011 | $C_D$ v2 [-] 2011 | D Area [m$^2$] 2011 | Drag Force [N] 2010 | Drag Force [N] 2011 |
|---|---|---|---|---|---|---|---|---|
| Ref. | | | | | | | | |
| 1 | 10.0 | (0.696) 0.348 | 0.332 | 1.1434 | 0.2901 | 0. 379 | 20.43 | 18.60 |
| | 20.0 | (0.689) 0.344 | 0.340 | 1.1434 | 0.2972 | 0.388 | 81.027 | 77.88 |
| | 30.0 | **(0.768) 0.384** | **0.386** | 1.1434 | 0.3376 | 0. 441 | **202.98** | **201.44** |
| Ref. | | | | | | | | |
| 2 | 10.0 | (0.624) 0.312 | 0.320 | 1.0761 | 0.2974 | 0.344 | 18.34 | 17.93 |
| | 20.0 | (0.688) 0.344 | 0.307 | 1.0761 | 0.2855 | 0.330 | 80.82 | 70.32 |
| | 30.0 | (0.720) 0.360 | 0.329 | 1.0761 | 0.3061 | 0.354 | 190.40 | 171.87 |
| Ref. | | | | | | | | |
| 3 | 10.0 | **(0.438) 0.219** | 0.255 | 1.0583 | 0.2406 | 0.269 | **12.82** | 14.26 |
| | 20.0 | (0.544) 0.272 | 0.287 | 1.0583 | 0.2713 | 0.303 | 63.90 | 65.74 |
| | 30.0 | (0.546) 0.273 | 0.286 | 1.0583 | 0.2700 | 0.302 | 144.04 | 149.10 |
| Ref. | | | | | | | | |
| 4 | 10.0 | | **0.230** | | | | | **12.86** |
| | 20.0 | (0.459) 0.229 | 0.252 | | | | 53.87 | 57.68 |
| | 30.0 | | 0.271 | | | | | 141.40 |

Obs.: The values were obtained from the estimated frontal area of 0.5 m$^2$ of the athlete in 2010 and 1 m$^2$ in the 2011 test. The numbers highlighted in bold are the maximum and minimum values found in each session. The colours green and orange represent an improvement or deterioration in performance, respectively. The blue represents the values found for the CD from experiment 3 for the new values calculated of the frontal area based on the technique of counting pixels of digital photographs.

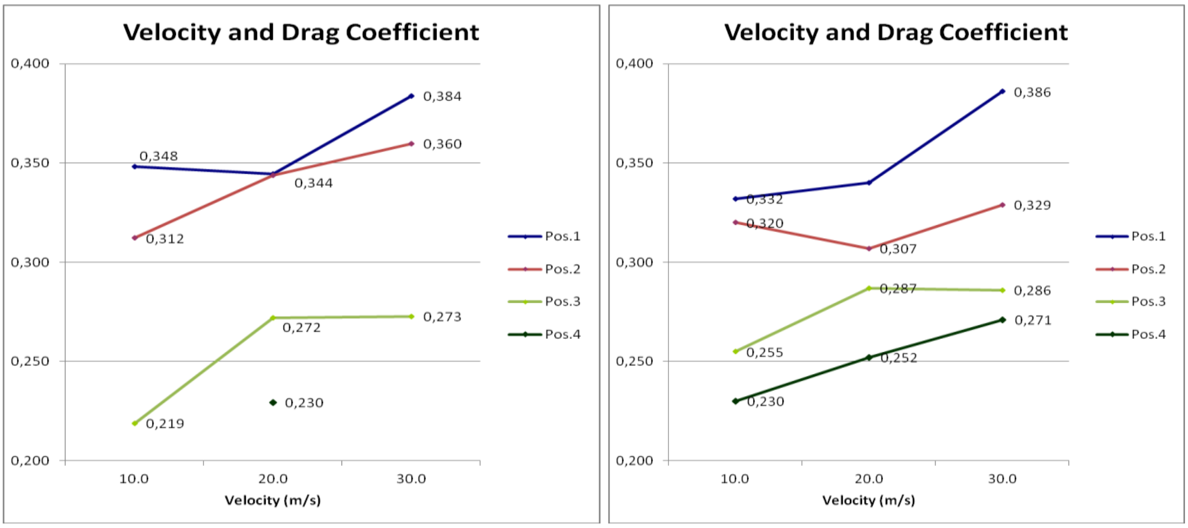
It can be seen from the photographic records that follow that the values presented with respect to each photo have already been corrected, enabling a direct comparison to be made. Similarly, these values were also used in the construction of comparative graphs between each campaign and configuration performed.

In relation to the sports equipment used by C2, the same jacket and helmet were worn for both the evaluative WT sessions, however, the rest of the kit (monoski, ski outriggers, goggles and gloves) differed from one campaign to the next. In addition to this equipment change, C2 also adopted the practice of using her jacket to cover the back part of the monoski seat during T3. More detailed descriptions of the positions assumed for the experiments, together with the recorded photos, can be found after the graphs that follow.

Figures 24 and 25 show the relationship between wind speed and drag force, while figures 26 and 27 present the relationship between wind speed and the drag coefficient generated by the individual.




**Figures 24 and 25** – Performance curves for **D** according to test stages performed in 2010 and 2011.




**Figures 26 and 27 –** Performance curves for $\mathbf{C_D}$ according to test stages performed in 2010 and 2011.

**Description of Positions**

**Lateral Photos Recorded during the WT Experiments**

*P1 – 10 m/s* – For the first position (neutral) in T2 (photo T2P1S1), the athlete positioned herself with her body trunk perpendicular to the ground. Her arms were held alongside the body with elbows bent (approx. 70 º) and positioned next to the trunk, with her hands holding the ski poles diagonally in relation to the ground and avoiding contact with it. In T3 (photo T3P1S1), it can be seen that the athlete maintained a slightly greater forward flexion of the trunk than in the first test, with arms held a little further back, causing the skis to be more raised in relation to the floor.

*P1 – 20 m/s* – In T2 (photo T2P1S2), the athlete reproduced a position almost equal to that assumed at 10m/s but with some subtle differences, such as a slight forward flexion of the neck and trunk and greater bending of the elbows. In T3 (photo T3P1S2), the athlete reproduced a position almost equal to that assumed at 10 m/s for the principal points of reference (head, arms, trunk, forearms and hands).

*P1 – 30 m/s* – In T2 (photo T2P1S3), the athlete held her trunk and arms just a little further forward, with the angle of the ski-tip ends of the ski poles changing, increasing the frontal area of exposure of the accessory. In T3 (photo T3P1S3), the athlete maintained her performance as with 20 m/s, but once again the alteration of angle of the ski-tip ends of the ski poles increased the frontal area of exposure for the equipment.

**Figure 28: Position 1 – Neutral Position**

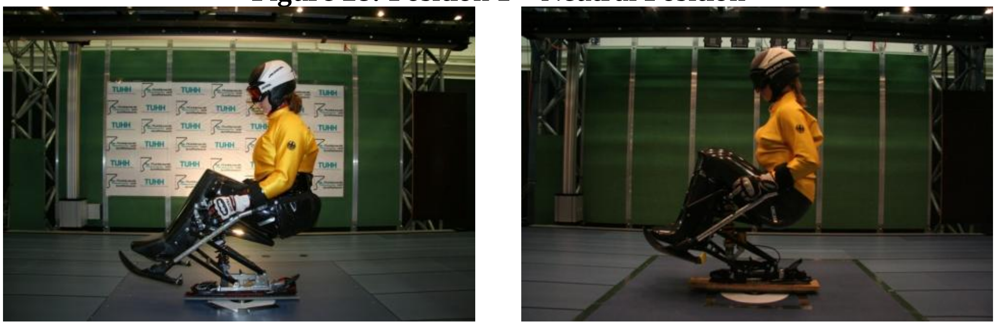


photo T2P1S1 – Drag Coeff. 0.348 **10 m/s** photo T3P1S1 – Drag Coeff. 0.332

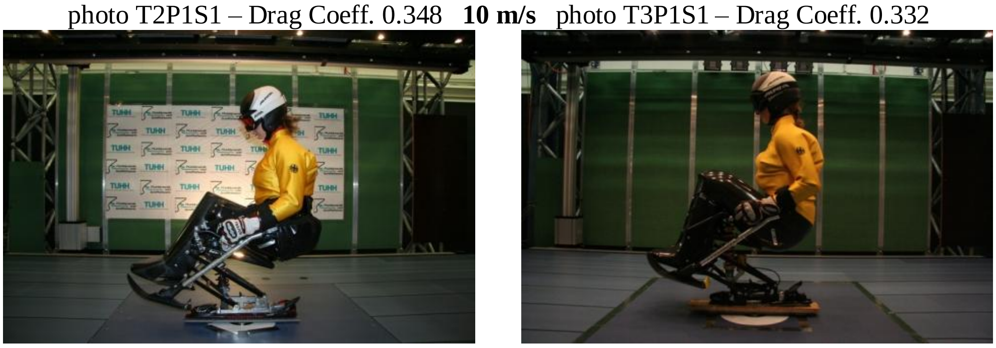


photo T2P1S2 – Drag Coeff. 0.344 **20 m/s** photo T3P1S2 – Drag Coeff. 0.340

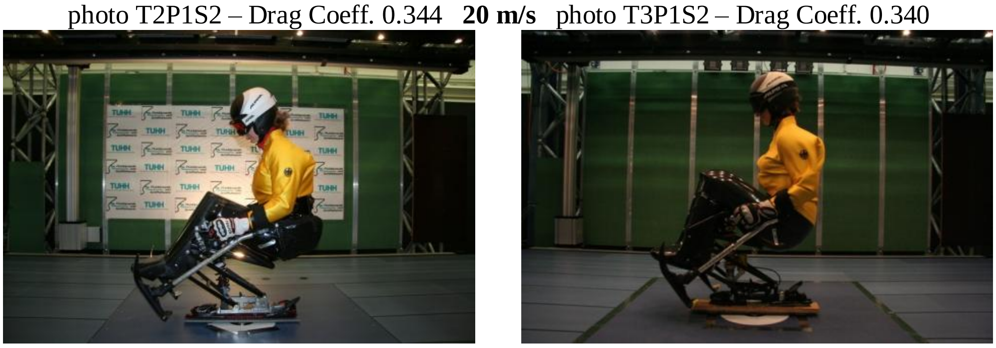


photo T2P1S3 – Drag Coeff. 0.384 **30 m/s** photo T3P1S3 – Drag Coeff. 0.386

*P2 – 10 m/s* – For the second position (run) in T2 (photo T2P2S1), the athlete assumed a slight forward flexion of the trunk (approx. 30º). Arms were nearly aligned with the trunk and elbows bent (approx. 60º) and positioned close to the body. Her forearms and hands were positioned alongside the thighs and lower legs, respectively. In T3 (photo T3P2S1), it can be seen that the athlete kept the forward flexion of the trunk (approx. 40º) as well as bent elbows (approx. 80º), with the arms slightly misaligned in relation to the trunk and the hands held by her legs.

*P2 – 20 m/s* – In T2 (photo T2P2S2), the athlete reproduced a position of the trunk almost equal to that assumed at 10 m/s but with less extension of the arms and elbows more flexed, allowing the hands to remain further back and elevating the ends of the ski poles from the ground. In T3 (photo T3P2S2), the athlete reproduced a position assumed at 10 m/s, with a slight elevation of the head and flexion of the elbows allowing the skis to be raised.

*P2 – 30 m/s* – In T2 (photo T2P2S3), the athlete reproduced a position almost equal to that assumed at 20 m/s, but with a subtle elevation of the arms. The ski-tip ends of the ski poles were raised, increasing the frontal area of exposure. In T3 (photo T3P2S3), the athlete reproduced a position as with 20 m/s, with only the arms being held a little further back and a greater flexion of the elbows.

**Figure 29: Position 2 – Run Position**


photo T2P2S1 – Drag Coeff. 0.312 **10 m/s** photo T3P1S1 – Drag Coeff. 0.320

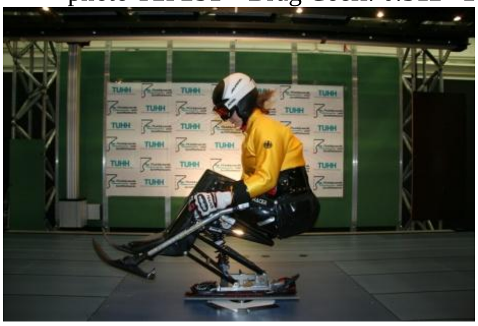



photo T2P2S2 – Drag Coeff. 0.344 **20 m/s** photo T3P2S2 – Drag Coeff. 0.307


photo T2P2S3 – Drag Coeff. 0.360 **30 m/s** photo T3P2S3 – Drag Coeff. 0.329

*P3 – 10 m/s* – For the third position (aggressive) in T2 (photo T2P2S3), the athlete adopted a position of maximum forward flexion of the trunk (approx. 45º). Her arms were perpendicular to the trunk, elbows almost fully extended and positioned close to the body at the height of the knees. Her forearms were further forward with the hands positioned well in front in relation to the line of the legs. In T3 (photo T3P3S1), it can be seen that the athlete assumed a maximum forward flexion of the trunk with elbows bent (approx. 60º). The arms were held slightly further back with the hands positioned just in front of the legs, keeping the ski-tips parallel.

*P3 – 20 m/s* – In T2 (photo T2P3S2), the athlete reproduced a position almost equal to that assumed at 10 m/s but with a subtle difference in position of the left arm bringing the ski pole a little higher than the right. In T3 (photo T3P3S2), the athlete reproduced a position almost equal to that assumed at 10 m/s for the principal points of reference (head, arms, trunk, forearms and hands).

*P3 – 30 m/s* – In T2 (photo T2P3S3), the athlete reproduced the position assumed as at 20 m/s, with slightly less flexion of the trunk position. In T3 (photo T3P3S3), the athlete maintained her performance as at 20 m/s, however, a slight elevation of the trunk and arms can be seen, and as a consequence also the hands and ski poles.

**Figure 30: Position 3 – "Agressive" Position**


photo T2P3S1 – Drag Coeff. 0.219 **10 m/s** photo T3P3S1 – Drag Coeff. 0.255


photo T2P3S2 – Drag Coeff. 0.272 **20 m/s** photo T3P3S2 – Drag Coeff. 0.287


photo T2P3S3 – Drag Coeff. 0.273 **30 m/s** photo T3P3S3 – Drag Coeff. 0.286

*P4 – 10 m/s* – The fourth position (extra) was not performed by the athlete in T2. In T3 (photo T3P4S1), the athlete assumed maximum forward flexion of the trunk (approx. 45º). The main change was in the differing positions of the arms, with the left arm held at right angles to the ground and the right arm being more elevated and lifting the ski-pole to a position above the line of the horizon (positive angle of attack).

*P4 – 20 m/s* – In T2 (photo T2P4S2), the athlete reproduced a position almost equal to that assumed for P3 with the ski poles held together in line. In T3 (photo T3P4S2), the athlete reproduced a position almost equal to that assumed at 10 m/s, but the left arm was advanced further forward.

*P4 – 30 m/s* – The fourth position was also not performed by the athlete in T2 at this speed. In T3 (photo T3P4S3), the athlete reproduced the position as at 20 m/s but allowed slight elevation of the right hand and advancing the left hand, having the effect of raising and moving forward the relevant ski poles, respectively.

**Figure 31: Position 4 – Extra Position**

**10 m/s** photo T3P4S1 – Drag Coeff. 0.230

photo T2P4S2 – Drag Coeff. 0.229 **20 m/s** photo T3P4S2 – Drag Coeff. 0.252

**30 m/s** photo T3P4S3 – Drag Coeff. 0.271

**Frontal photos recorded after the WT experiments**

*P1 – No wind* – It can be seen from the photo (T2P1) in the first session that the athlete's head was rotated to the left and that her shoulders were not level. Her arms are held alongside her body and positioned closely. Elbows and hands were slightly out of line whilst holding the *ski poles,* with the ski-tips being prevented from coming into contact with the ground. The trunk was not well aligned with the monoski. In T3 (photo T3P1), a better equilibrium in the posture of C2 can be seen than for the first campaign. It was possible from the photo taken to create a diagram (T3P1v2) for calculation of the area.

**Figure 32: Position 1 – Neutral Position**

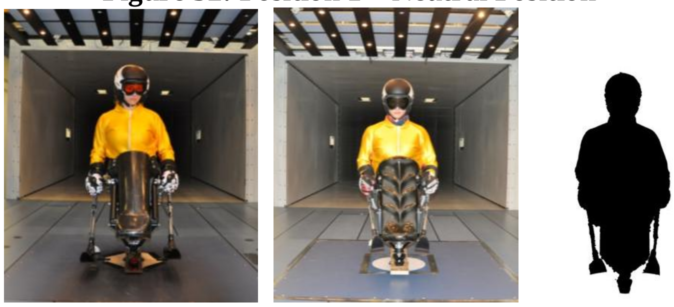


photo T2P1 photo T3P1 T3P1v2

*P2 – No wind –* It can be seen from the photo (T2P2) in T2 that the athlete's head was rotated to the left and that her shoulders were not level. Her arms were held alongside her body, however only the left arm was positioned close. The trunk was not well aligned with the monoski. Elbows and hands were out of line whilst holding the *ski poles*, with the ski-tips being prevented from coming into contact with the ground. In T3 (photo T3P2), it was observed that the posture of the athlete was much more balanced than for the first campaign. It was possible from the photo taken to create a diagram (T3P2v2) and calculate the area of the athlete complete with monoski in P2.

**Figure 33: Position 2 – Run Position**

photo T2P2 photo T3P2 T3P2v2

*P3 – No wind –* It can be seen from the photo (T2P3) in T2 that the athlete's head was aligned with the monoski and that her shoulders were level. Her arms were projected to the front and together with the legs. Elbows and hands were kept level whilst holding the ski poles and keeping the ski-tips elevated. The trunk was aligned with the monoski. In T3 (photo T3P3), a difference can be seen in the execution of the position when compared to the first campaign. The head of athlete C2 leaned to the left and her shoulders were not level. The arms were held alongside the legs and the trunk was slightly out of line with the structure of the monoski. From the photo taken it was possible to produce the diagram (T3P3v2) and calculate the area of the athlete complete with monoski in P3.

**Figure 34: Position 3 – "Agressive" Position**

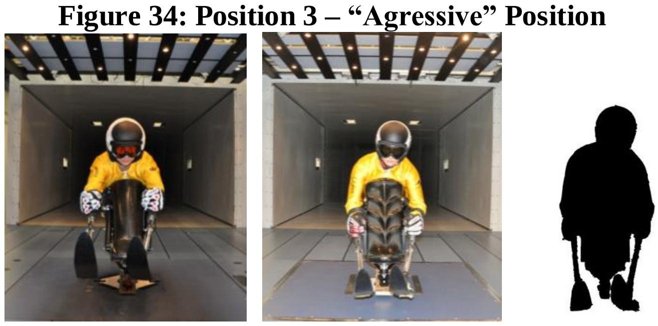


photo T2P3 photo T3P3 T3P3v2

*P4 – No wind* – A photo was taken for the 1st test session only (photo T2P4) and showed the athlete with head aligned with the longitudinal axis, and with shoulders level. Her arms were projected to the front whilst securing the ski poles, with the ski-tips in front of her body and crossed.

**Figura 35: Position 4 – Extra Position**

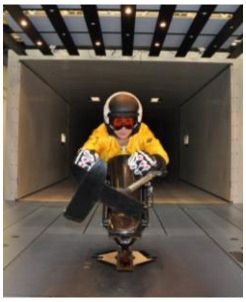


photo T2P4

The general results of the anthropometric evaluation, the treatment of the photographic records, and the questionnaires and field notes completed by the athletes and trainer for both campaigns have now been presented. We would now like to put forward, in addition to the individual results presented in relation to tests performed on the ergometric treadmill and bicycle, and in the wind tunnel, a follow-up of the individual analysis by means of a discussion for the athlete in question.

### 2.2.2 Human Performance - Discussion

**Objectives Assessment**

The evaluation process was conducted with the intention of increasing the range of information and understanding of the performance structure that affects the world of the athletes from the *DPS*. It also aimed to analyse and compare individual results, contrasting them with other team members and to eventually relate these to other Paralympic athletes (e.g. wheelchair sports).

This athlete, born in January 1993, is a relatively recent newcomer to training with the *DPS*, but participated in the 2010 Paralympic Winter Games, winning a bronze medal in the Super-G and finishing in 4th place in the Slalom and Combined competitions in the sitting category. Her conduct over the course of these experimental studies was exemplary, however, she faced some difficulties for both tests in the 1st campaign but was able to overcome these in the 2nd campaign. She presented interesting and respectable results for this competitive sport, as well as for the scientific community.

**Anthropometric Assessment**

From the anthropometric measurements taken, it was observed that the volunteer reduced her body weight from 47kg to 43kg during the period between the two evaluative campaigns. As a consequence, this altered her body mass index with it reducing to 19.11kg/m$^2$, however, remaining within the range considered as normal according to “The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults” (National Institutes of Health, 2000).

Data collected during the 2nd campaign included measurement and recording of the seated height (107cm) and arm-span (162cm) of C2. From this information it was possible to determine her trunk index (Cormic Index and Relative Arm-span). C2 is the only female representative from the sport among the sit-ski category athletes from the 2nd campaign. Her Cormic Index of 54.1 is considered to be macrocormic and her relative arm-span of 108 is quite large, even when compared to the male athletes of the team, being inferior only to that of athlete C1.

**Physiological Assessment**

These anthropometric characteristics can be considered advantageous for her physical preparations in terms of physiology. Her trunk size and larger relative arm-span are beneficial to the performance of Alpine Skiing as the trunk does not project excessively to the vertical, whilst long arms can provide better support on courses that include bends. The athlete can improve aerobic and metabolic fitness by increasing muscle mass on the trunk and upper limbs, whilst giving minimal interference to aerodynamic performance. It may also be seen as a positive aspect giving greater coordinative predisposition to maintaining the desired skiing postures.

The spiroergometry evaluation carried out to check the fitness condition of this athlete produced consistent and coherent results without exposing her to risk. Her performances in 2010 and 2011 were similar in as much as she continued the test until the same stage, however, she was able to perform this stage for 1min 50s longer during the 2nd campaign. Little difference was seen in the $HR_{max}$ between T1 and T4. It can be said that the physiological performance of C2 continues to improve as her $\dot{V}O_2$ was superior in the 2011 evaluation when compared to 2010, and additionally, she could continue for more time than in 2010. The $\dot{V}O_2$ values presented by C2 were 1607ml/min (34.19ml/kg/min) in the 1st campaign and 1768ml/min (37.61ml/kg/min) in the 2nd campaign. Although this test protocol differs from those adopted by other authors in their evaluations, as detailed by (Bhambhani, 2002) in Table 8, her results are comparable with them. It should be noted that the results encountered in Table 8 refer to trained and untrained individuals in wheelchair sports.

**Table 8 – Peak Aerobic Power in Trained and Untrained Female Wheelchair Athletes with Paraplegia**

| Study | Mode | n | ISMGF classification | Lesion | $VO_2$ (L/min) | $VO_2$ (ml/kg/min) | HR (beats/min) |
|---|---|---|---|---|---|---|---|
| **Trained** | | | | | | | |
| Schmid et al. | WERG | 13 BB | I-III | T1-L5 | 1. 90 | 33.7 | 181 |
| Vanlandewijck et al. | WCT | 10 BB | I | T3-T12 | 1.67 | 25.5 | |
| Veeger et al. | WCT | 8 WA | IC,III-V | C7/8-S1 | 1.22 | 20.7 | 172 |
| **Untrained** | | | | | | | |
| Schmid et al. | WERG | 10 UT | | T1-L5 | 1.09 | 18.3 | 180 |

ACE – arm crank ergometer; BB – wheelchair basketball players; ISMGF International Stoke Mandeville Games Federation functional classification; n – sample size; RR – wheelchair road racers, $VO_2$ - Oxygen Uptake; UT – untrained participants; WA – wheelchair athletes (mixed group of athletes); WCT – wheelchair mounted on treadmill; WERG – wheelchair ergometer. Table incomplete, taken from an article by Yagesh Bhambhani (2002).

In assessing the functional capacity of C2, we must look at the mechanical and physiological performance and the relationship between them (Wüpper, 2002). Athlete C2 was able to advance to the 3rd stage (60W) in experiment n.1 and continued there for 1min 10s. From a physiological perspective she was able to generate 589.37W, representing an efficiency of 10.18%. In T4, C2 was once again able to reach the 3rd stage (60W) and this time to complete it. From a physiological perspective she was able to generate 653.79W, representing an efficiency of 9.18%, with this being a lower value than in the 1st campaign (Vinagre *et al*, 2012).

When comparing the HR reached with the maximum pre-determined HR according to the Karvonen formula (Robergs 2002, Policarpo 2004), the peak HR reached by this volunteer in the two evaluative campaigns was equivalent to the pre-determined $HR_{max}$. Follow-up measurements for C2 taken 3 minutes after both tests were ended showed that her HR remained above 140bpm (153bpm and 148bpm, respectively), indicating that although she has good cardiovascular fitness, there is still some room for improvement. Table 8 verifies the results presented in these experiments, although the ages of the volunteers who performed those tests are not included.

A difference in tested lactate concentrations for C2 occurred in the post-test recuperation period for both campaigns. Despite the recorded level of lactate being higher at the end of testing in the second campaign (8.8mmol/l) as compared to the first, the volunteer's response can be considered to be better as recovery took place quicker and the lactate level readings were less subject to fluctuation.

**Aerodynamic Evaluation**

The aerodynamics evaluation was intended to take account of the amount of drag produced by the athletes and generated innovative results without exposing C2 to risk. The performance of C2 over the two campaigns was very similar, although she was still able to improve her results in the 2011 evaluation. She conducted the 2011 test within the set parameters and recording lower values in almost all the positions carried out. As can be seen in Table 7 and in Figures 24, 25, 26 and 27, the values obtained in the test were quite coherent (Vinagre *et al*, 2012).

In a comparison of the results for **D** in 2011 with those of 2010, it can be seen that C2 was able to reduce the drag produced by the posture offering the most resistance (P1), except at 30m/s where it remained virtually the same. One can also state categorically that there was deterioration in the test performance of P3 in 2011 in relation to 2010. In the other previously performed positions, the athlete was able to improve her performance in 2011 when compared to the previous campaign, as can be seen in Table 7 and Figures 24 and 25.

When comparing the $\mathbf{C_D}$ values between the two years, however, a certain inconsistency was found as only half the positions carried out produced the expected results as the wind speed increased. This was not the case in T2 for P1 and T3 for P2 when a decrease in the $\mathbf{C_D}$ produced by the athlete occurred when moving on to the second stage (20m/s), and again in both T2 and T3 for P3 when no decrease occurred in the $\mathbf{C_D}$ presented by C2 when moving on to the third stage (30m/s). Incorporating calculation of the $\mathbf{C_D}$ according to the frontal area of the individual in the 2nd campaign in 2011 brought with it even more accurate values. The figures for the **D Area** of C2 calculated from the frontal area at 30m/s represents $0.441m^2$ in P1, $0.354m^2$ in P2 and $0.302m^2$ in P3.

**Postural Evaluation**

**Analysis of Lateral Photos**

In the analysis of postures performed by C2 during both campaigns, it should be noted that in T3 the athlete adopted the practice of using her jacket to cover the top edge of the monoski seat.

In P1, in 2010, the volunteer carried out the desired posture allowing her trunk to flex forward with the advancing of the test stages and altering her head position. In contrast, performing P1 in 2011, her posture remained very consistent with virtually no change as the stages advanced. Comparing the postures adopted in this campaign with the previous, a fundamental change in head position can be seen (head held higher and facing more to the front in 2011), in trunk position and placement of arms, which in 2011 were positioned further back in relation to the longitudinal axis of the body.

In P2, it can be seen that in 2010 C2 showed a subtle variation in trunk positioning and in her arms. In 2011, C2 this variation in positioning of the trunk and arms continued, although less so. When comparing postures between the two campaigns we can see that in 2011, C2 displayed less trunk flexion but more elbow flexion than the previous year.

In P3, it is observed that C2 produced a homogeneous performance, with slightly less forward flexion of the trunk and ski poles subtly raised (due to wind pressure). In 2011, C2 carried out the entire sequence of positions with no significant postural changes. Comparing her stance between the two campaigns, it can be seen that C2 adopted a position of leaning further forward with arms projected more to the front and head held lower in 2010, as compared to the following year, when she maintained greater flexion of her elbows.

Few comparisons can be made for P4 as this position was only carried out at the wind speed of 20m/s by athlete C2 in 2010. In the test conducted the following year, despite the outriggers being held in differing positions, C2 was able to perform and maintain the trunk position easily, slightly varying the arms from one stage to another. When comparing the postures between campaigns it can be seen that C2 delivered two completely distinct performances. In 2010, her trunk was flexed forward over the legs, with eyes directed to the ground and both outriggers held side-by-side and as far to the front as possible. In 2011, the trunk flexion was restricted by the lay-out of the new sit-ski, the eyes were directed more to the front than the ground and the outriggers were not held parallel, although still positioned to the front.

**Analysis of frontal photos**

An analysis of the postures held by C2 in the frontal plane for the two campaigns demonstrates that for both 2010 and 2011 in P1, the volunteer was able to carry out and repeat the posture with minimal alterations in the positioning of the head, trunk and outriggers, which are held closer to the body and higher. The difference between the two campaigns is more striking in P2, as in 2010 C2 was very unbalanced in her attempts to achieve the required posture. This was not the case in 2011, where C2 sought to continue the stable performance realized in P1. A difference in performance can be seen in P3 for each campaign. Although the arms and outriggers are held closer to the body in 2011, C2 demonstrates an imbalance in the positioning of her trunk. In 2010, despite maintaining a better positioning of the trunk, the outriggers are misaligned with the central axis of the sit-ski and the body of the athlete. The variations in the frontal area generated by C2 are seen more clearly when comparing the additional diagrams created for the positions P1, P2 and P3.

**Questionnaires**

The questionnaires applied in the $2^{nd}$ campaign provide exact details of the beginning of the training season (August) for C2 and the overall progress of her training year. C2 trains on a daily basis throughout the year and on some days carries out two different forms of training session. In the period from March to June after the competitive season has ended, C2 conducts 7 weekly workouts with the emphasis being on endurance work, and 2-4 additional sessions focused on strength work, whilst still dedicating time to more recreational activities. In the period from June to September, the strategy employed in the previous quarter is continued but increasing the volume of aerobic training (8 times per week). The volume of training grows in the period of Sept/October to December with an increase in the sports practiced reaching 16 weekly sessions of training. It is the technical training that consumes the most time and can extend to 2.5h in duration. The competitive season takes place in the months from Dec/January to March, and C2 tries to divide her training schedule so that she can dedicate 70-80% of her time to physical workouts and the remaining 20-30% to technical and tactical training.

Her best results achieved so far in the world of Alpine Skiing (2011 World Championship Sestriere/ Italy), took place between the two evaluative campaigns, when she finished in $1^{st}$ place for the Slalom and Giant Slalom races. These demand a greater degree of manoeuvrability than for the Downhill race and Super-G, in which she finished in $4^{th}$ place for both events. It is important to note that she suffered a concussion injury during the World Championships.

C2 has a reasonable awareness of her own physical condition and high self esteem. She indicated in the questionnaire that she feels comfortable in her wheelchair and is not generally in pain. In the replies related to the WT evaluation, it can be seen that C2 was able to safely and comfortably conduct the test. Although she did not complete all of the stages in T2, she thought the level of demand for the test to be relatively easy. She believes the test results to be important but does not know exactly how they can be incorporated into her performance and training routine. Her completion of the post-test questionnaire confirmed what she had stated in the pre-test questionnaire, but added to the information that she feels the most enjoyable test position she performs to be P4.

From responses related to the investigation conducted at the Physiology Laboratory, it can be seen that C2 was able to safely perform the test, although it was observed that she did not do so comfortably, principally in T1. According to her self-perception and from a respiratory point of view, she could carry out the test well and comfortably, particularly in the posture requiring the trunk to have forward flexion. Although she found the level of demand for the test relatively difficult, principally in T4, she was able to perform for a longer time than in T1. She believes these results to be more important than those found in the WT, in terms of her performance and training. She also believes that her training has been adapted to take into account a number of improvements from the sessions. In the post-test questionnaire, C2 confirmed her statements made pre-test and believes that she is currently in a period of very good physical fitness.

**2.3 Case number 3/ Volunteer (C3)**

The third case is an athlete from the male alpine ski team, born on 20/02/85, and having a disability classification of LW10-1 in the sitting skiers (monoskiers) category. He suffered a motorcycle accident in 2002, causing a fracture at the height of the 5th thoracic vertebra (T5), making him paraplegic. His deficiency is considered to be moderate, preventing movement of his legs and part of his body trunk. He began to monoski in 2006 and completed an initial monoski course in 2007. In 2008 he participated for the first time in the Eurocup. He is the newest member of the *DPS* and is still in an early developmental process to improve results within the sport.

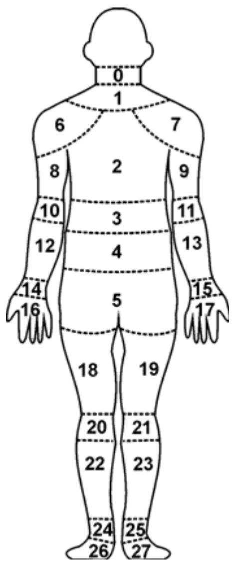
As can be seen from Tables I and II (p.78), C3 is 183cm tall and weighed 63kg at his last evaluation, giving him a Body Mass Index of 18.81kg/m$^2$. Measurements of seated height and arm-span of the participant were also taken during the latter evaluative campaign, which allowed his Cormic Index and relative arm-span to be determined. The individual assessment of C3 also included important information related to his perceived discomfort through use of the Body Discomfort Diagram presented in Figure 34.

**Figure 36: Body Discomfort Diagram**

**Body Discomfort Diagram**

**1. No discomfort**
**2. Some discomfort**
**3. Moderate discomfort**
**4. High discomfort**
**5. Unbearable discomfort**

| | |
|---|---|
| 0. Neck | 1 2 **3** 4 5 |
| 1. Cervical | 1 2 **3** 4 5 |
| 2. High back | 1 **2** 3 4 5 |
| 3. Middle back | **1** 2 3 4 5 |
| 4. Low back | **1** 2 3 4 5 |
| 5. Hip | **1** 2 3 4 5 |
| 6. R. Shoulder | 1 2 3 **4** 5 |
| 7. L. Shoulder | 1 2 **3** 4 5 |
| 8. R. Arm | 1 2 3 **4** 5 |
| 9. L. Arm | 1 **2** 3 4 5 |
| 10. R. Elbow | 1 2 3 **4** 5 |
| 11. L. Elbow | **1** 2 3 4 5 |
| 12. R. Forearm | **1** 2 3 4 5 |
| 13. L. Forearm | **1** 2 3 4 5 |
| 14. R. Wrist | **1** 2 3 4 5 |
| 15. L. Wrist | **1** 2 3 4 5 |
| 16. R. Hand | **1** 2 3 4 5 |



According to Corlett and Wilson, 1986

| | |
|---|---|
| 17. L. Hand | **1** 2 3 4 5 |
| 18. R. Thigh | 1 **2** 3 4 5 |
| 19. L. Thigh | 1 **2** 3 4 5 |
| 20. R. Knee | 1 **2** 3 4 5 |
| 21. L. Knee | 1 **2** 3 4 5 |
| 22. R. Leg | **1** 2 3 4 5 |
| 23. L. Leg | **1** 2 3 4 5 |
| 24. R. Ankle | **1** 2 3 4 5 |
| 25. L. Ankle | **1** 2 3 4 5 |
| 26. R. Foot | **1** 2 3 4 5 |
| 27. L. Foot | 1 2 3 4 5 |

**2.3.1 Tests**

In the first campaign, C3 was the third volunteer to complete the ergometric treadmill test and the fifth in the wind tunnel. For the second campaign, he was the fourth participant to complete both the ergometric and aerodynamics testing. C3 had never taken part in this type of evaluative campaign involving spiroergometry prior to 2010. He tried to follow the standard protocol for tests 1 and 4 (T1 and T4), however, he did find T1 to be quite difficult. The athlete was also unfamiliar with the wind tunnel testing carried out in tests 2 and 3, but was able to follow the standard protocol and complete all of the pre-planned steps.

**Cardiopulmonary Test**

**Preparations; Control; Immediately before, During, After the test; Recovery**

The initial load encountered for test number 1 (T1) was 8.6N and for test number 4 (T4) was 8.02N. The blood sample taken prior to both T1 and T4 showed a lactic acid concentration of 0.9mmol/L. The cardiac electrical activity of the volunteer was monitored closely during testing, together with the consistency of the recorded physiological values to ensure that none of the monitored recordings showed any warnings signs. Both the test sessions were brought to an end at the request of the athlete, having reached his limit of endurance. New blood samples were collected immediately at test end, and again 3min. and 5min. after the end, with these values being presented in Tables 9 and 10. After removal of the mouthpiece/mask, the participant was asked about the nature and intensity of the limiting symptoms, with the replies being recorded on a standard form. Routine post-tests were conducted during the recovery period to ensure that both ECG and systemic blood pressure measurements returned to normal before the release of the volunteer, and the official ending of the test session.

**Results of Cardiopulmonary Tests 1 and 4**

The volunteer was required to pass a pre-test for both evaluative campaigns before being allowed to take part in the actual testing session. The readings for $\dot{V}O_2$, HR and load values obtained from the spiroergometry are listed in Table 9 and 10 and in Figures 37, 38, 39 and 40.

**Tables 9 and 10 – Results of Tests 1 and 4 for Athlete C3**

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 77 | 217 | 0.742 | 71.74 | 0.00 | 0.9 |
| 3 | 20 | 151 | 1487 | 0.864 | 506.19 | 3.95 | |
| 3 | 40 | 168 | 2222 | 0.957 | 774.41 | 5.17 | |
| 2min. 48s | 60 | 187 | 2380 | 1.144 | 867.66 | 6.92 | |
| | | | | | | | |
| after Stop | | 191 | | | | | 11.5 |
| 1 | | 169 | | | | | |
| 2 | | 156 | | | | | |
| 3 | | 142 | | | | | 11.9 |
| 4 | | 136 | | | | | |
| 5 | | 130 | | | | | 11.5 |

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 68 | 328 | 0.885 | 112.17 | 0.00 | 0.9 |
| 3 | 20 | 124 | 1323 | 1.025 | 468.63 | 4.27 | |
| 3 | 40 | 155 | 1704 | 1.017 | 602.57 | 6.64 | |
| 3 | 60 | 169 | 2180 | 1.140 | 794.09 | 7.56 | |
| 48sec. | 80 | 174 | 2251 | 1.216 | 834.63 | 9.59 | |
| | | | | | | | |
| after Stop | | 172 | | | | | 7.8 |
| 1 | | 154 | | | | | |
| 2 | | 132 | | | | | |
| 3 | | 123 | | | | | 8.7 |
| 4 | | 113 | | | | | |
| 5 | | 108 | | | | | 8.3 |

$P_N$ – Mechanical output, HR - Heart Rate, $VO_2$ - Oxygen Consumption, RQ - Respiratory Quotient, $P_B$ Gross output, e - equivalent $P_N/P_B$, LA – Lactate.

**Figures 37, 38, 39 and 40 – Results of Spiroergometry (tests 1 & 4) for athlete C3**

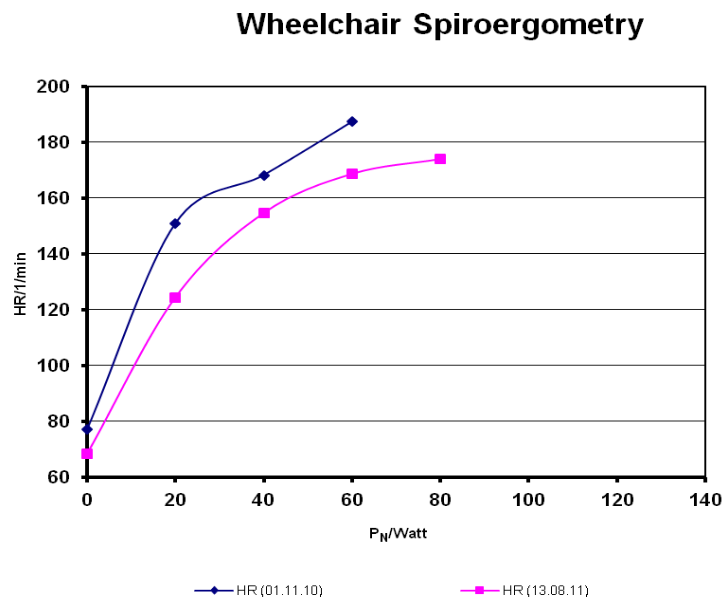



**Figure 37:** HR performance curves in relation to stage of testing, conducted in 2010 and 2011.

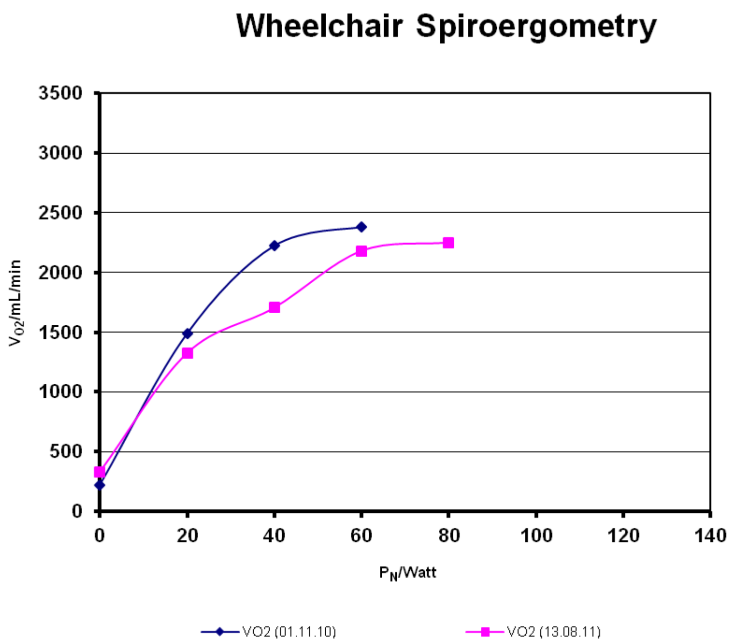



**Figure 38:** $\dot{V}O_2$ performance curves in relation to stage of testing, conducted in 2010 and 2011.

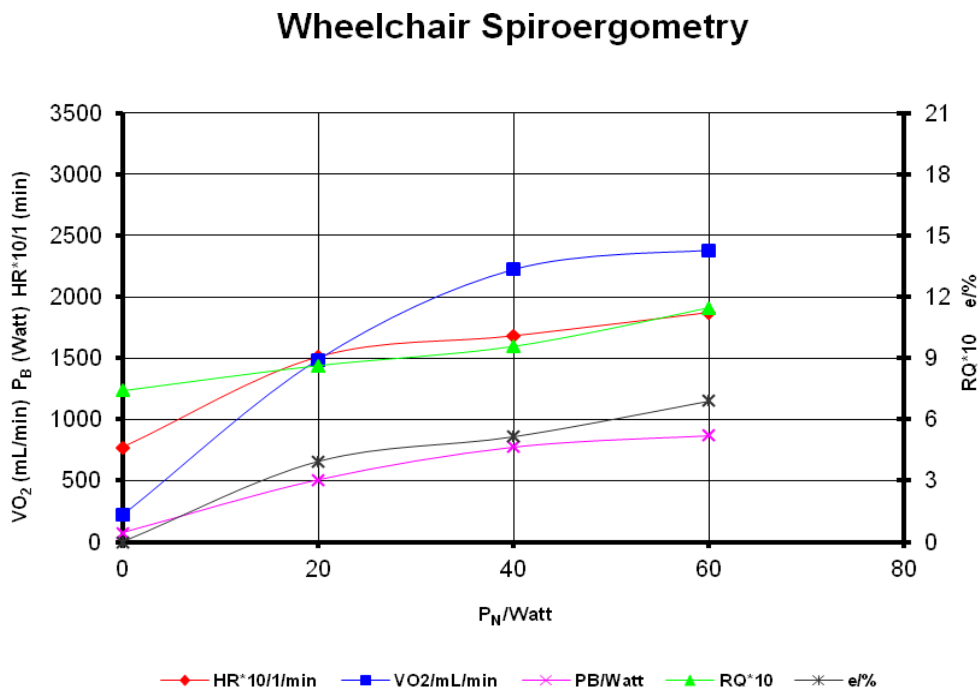



**Figure 39 –** Physiological data recorded during Test 1 in 2010.
Performance curves for HR, $\dot{V}O_2$, $P_B$, RQ and "e", respectively.

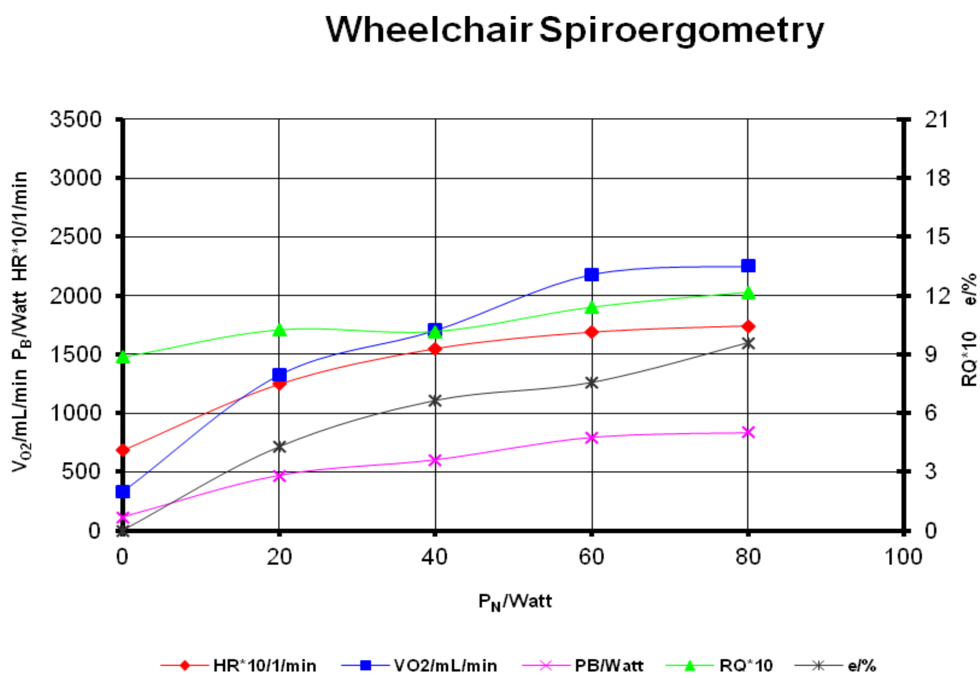



**Figure 40 –** Physiological data recorded during Test 4 conducted in 2011.
Performance curves for HR, $\dot{V}O_2$, $P_B$, RQ and "e" respectively.

Athlete C3 encountered some difficulty in maintaining a long duration test performance in the 1st campaign. He advanced until the 3rd stage but was unable to complete the entire time period of 3 minutes for this. From a biomechanical outlook, the athlete found it difficult to maintain a good posture, with his trunk tending bend initially to the front, and subsequently to the front and right. The frequency of his arm propulsion varied as the stages advanced in T1, presenting an irregular rate (1st stage 72 strokes/min, 2nd stage 81 strokes/min and 3rd stage 87 strokes/min). The highest load achieved by the athlete in T1 was 60W reached during the 3rd stage, whilst for test T4 he reached 80W when he advanced into the 4th stage. He presented a $\dot{V}O_2$ of 2380ml/min. and a lactate level of 11.5mmol/L immediately after the test end for T1, followed by a lactate reading of 11.9mmol/L from the 2nd blood collection after 3 minutes and 11.5mmol/L from the 3rd blood collection after 5 minutes.

In the 2nd campaign, he was able to complete the 3rd stage with a more comfortable posture and without leaning excessively to one side or the other, and advanced into the 4th stage by 48sec. Once again, the frequency of his arm propulsion varied as the stages advanced, presenting an irregular stroke rate of 65 strokes/min for the 1st stage, 69 strokes/min for the 2nd stage, and 74 strokes/min for the 3rd stage. He presented a $\dot{V}O_2$ of 2251ml/min. and a lactate level of 7.8mmol/L immediately after the test end, followed by a lactate reading of 8.7mmol/L from the 2nd collection after 3 minutes and 8.3mmol/L from the 3rd collection after 5 minutes (Figure 41). The maximum HR, measured immediately after each test came to an end, was 187bpm for the first campaign and 174bpm for the 2nd campaign, as presented in Tables 9 and 10.

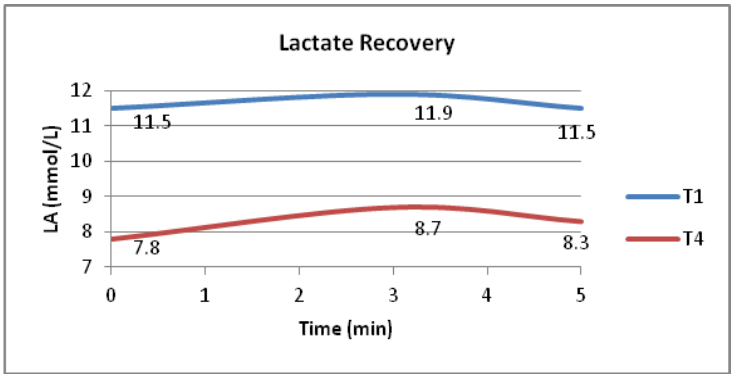



**Figure 41 –** Physiological data (lactate) after Test 1 and Test 4 conducted in 2010 and 2011 respectively.

**Aerodynamic Test**

**Preparations; Control; Immediately before, During, After the test; Recovery**

The volunteer was monitored closely during testing in relation to both his personal safety and his performance of the test positions to be carried out. No contact occurred during testing between the support platform for the monoski and the WT floor. C3 consistently performed and repeated every position requested of him, showing no signs of fatigue during testing. The consistency of the force values together with the respective photographic records for the evaluated settings, were also ensured. The endpoint for both tests was carried out by the technical team who were responsible for control management of the WT system and for the timing of photographic records for each position performed, as well as the interval between changes of velocity and position.

The athlete was asked about his experience of the nature and intensity of this evaluation method after completion of the test, and voiced no complaints. Spontaneous comments made by the athlete during T2 were recorded in field notes, and a questionnaire was applied both before and after the evaluation for T3.

**Results of Aerodynamics Tests 2 and 3**

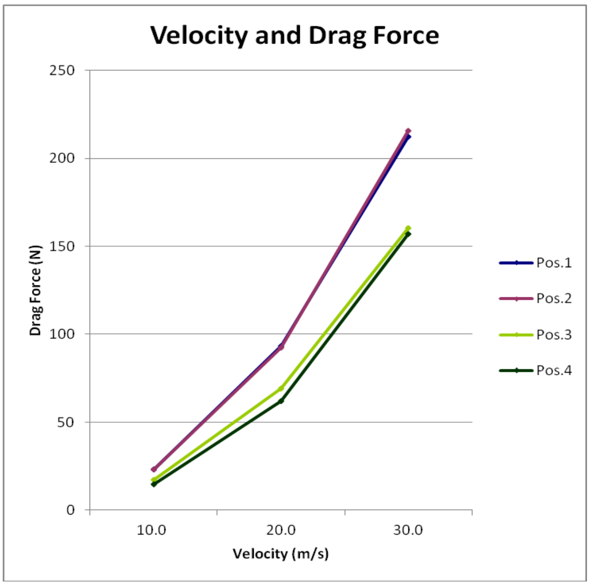
C3 was able to complete both the WT tests in accordance with the outlined protocol, as can be seen in Table 11. In terms of coordination, he was also able to perform, maintain and repeat the requested positions with much precision. The largest **D** presented by him for each of the two tests was 215.58N for T2 and 213.65N for T3, both whilst adopting P2 at 30 m/s. His lowest **D** value for the T2 was 14.79N whilst in P4 at 10 m/s, and in T3 the lowest value found was 13.75N in P3 at 10 m/s. The largest $\mathbf{C_D}$ presented by him in T2 was 0.814 (0.407) in P2 at 30 m/s, and for T3 this value was 0.408 using the same configuration. His lowest $\mathbf{C_D}$ value for the first test was 0.502 (0.251) whilst in P4 at 10m/s, and for T3 the lowest $\mathbf{C_D}$ value was 0.244 in P3 at 10m/s.

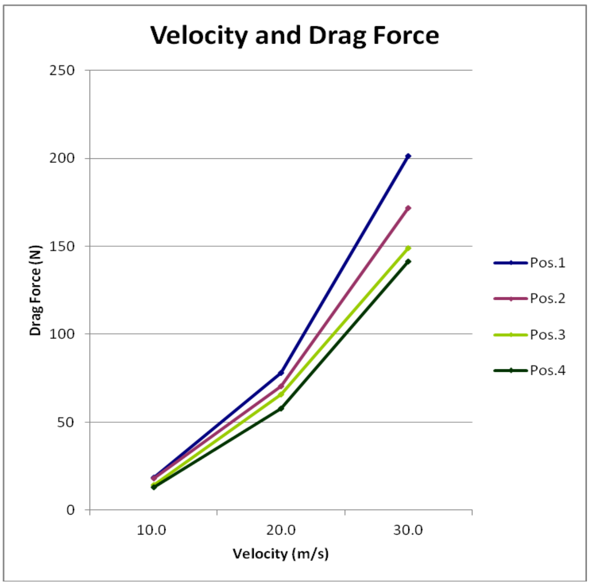
**Table 11 – Wind Tunnel Test Data for C3**

| Pos. | Velocity [m/s] | $C_D$ [-] 2010 | $C_D$ [-] 2011 | Area [m$^2$] 2011 | $C_D$ (V2) 2011 | D Area [m$^2$] 2011 | Drag Force [N] 2010 | Drag Force [N] 2011 |
|---|---|---|---|---|---|---|---|---|
| Ref. | | | | | | | | |
| 1 | 10.0 | (0.791) 0.395 | 0.381 | 1.3495 | 0.2825 | 0.514 | 23.33 | 21.49 |
| | 20.0 | (0.792) 0.396 | 0.385 | 1.3495 | 0.2855 | 0.519 | 93.25 | 88.73 |
| | 30.0 | (0.802) 0.401 | 0.399 | 1.3495 | 0.2959 | 0.538 | 212.40 | 209.39 |
| Ref. | | | | | | | | |
| 2 | 10.0 | (0.787) 0.393 | 0.401 | 1.3909 | 0.2881 | 0.557 | 23.12 | 22.56 |
| | 20.0 | (0.786) 0.393 | 0.398 | 1.3909 | 0.2864 | 0.553 | 92.53 | 91.60 |
| | 30.0 | **(0.814)** 0.407 | **0.408** | 1.3909 | 0.2933 | 0.567 | **215.58** | **213.65** |
| Ref. | | | | | | | | |
| 3 | 10.0 | (0.601) 0.300 | **0.244** | 1.3110 | 0.1864 | 0.319 | 17.38 | **13.75** |
| | 20.0 | (0.592) 0.296 | 0.284 | 1.3110 | 0.2167 | 0.372 | 69.38 | 65.34 |
| | 30.0 | (0.607) 0.303 | 0.283 | 1.3110 | 0.2156 | 0.371 | 160.24 | 148.12 |
| Ref. | | | | | | | | |
| 4 | 10.0 | **(0.502)** 0.251 | 0.306 | 1.0868 | 0.2819 | 0.332 | **14.79** | 17.24 |
| | 20.0 | (0.526) 0.263 | 0.314 | 1.0868 | 0.2894 | 0.341 | 61.98 | 72.37 |
| | 30.0 | (0.592) 0.296 | 0.322 | 1.0868 | 0.2965 | 0.349 | 156.87 | 168.79 |

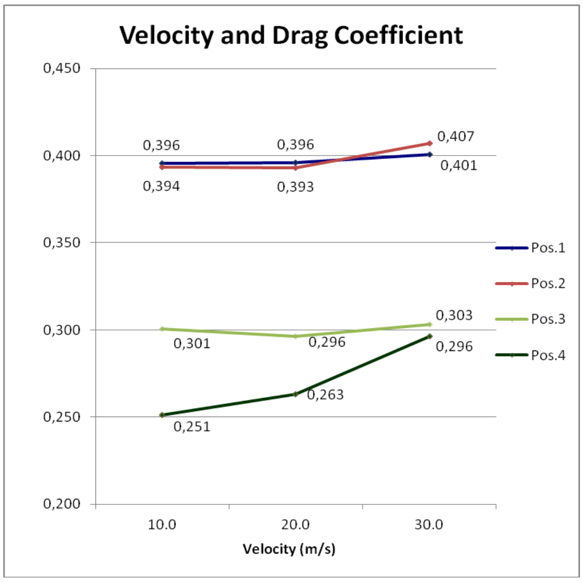
Obs.: The values were obtained from the estimated frontal area of 0.5m$^2$ of the athlete in 2010 and 1m$^2$ in the 2011 test. The numbers highlighted in bold are the maximum and minimum values found in each session. The colours green and orange represent an improvement or deterioration in performance, respectively. The blue represents the values found for the CD from experiment 3 for the new values calculated of the frontal area based on the technique of counting pixels of digital photographs.

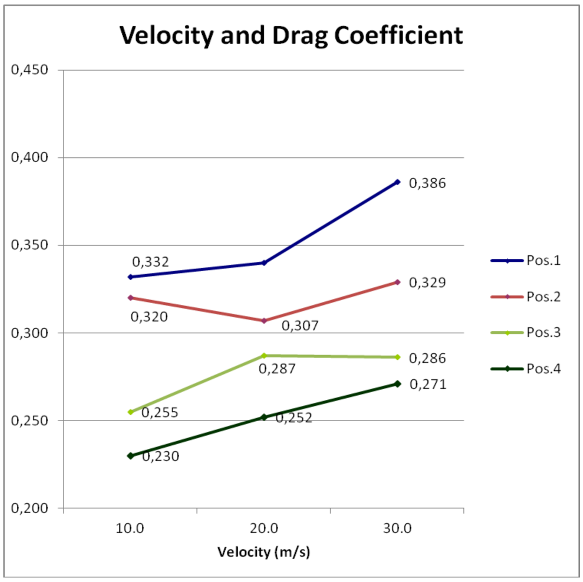
It can be seen from the photographic records that follow that the values presented with respect to each photo have already been corrected, enabling a direct comparison to be made. Similarly, these values were also used in the construction of comparative graphs between each campaign and configuration performed.






**Figures 42 and 43 –** Performance curves for **D** according to test stages performed in 2010 and 2011.






**Figures 44 and 45 –** Performance curves for **CD** according to test stages performed in 2010 and 2011.

**Description of Positions**

**Lateral Photos Recorded during the W-T Experiments**

*P1 – 10m/s* – In T2 (photo T2P1S1), the athlete presented his trunk with slight forward flexion. His arms are held alongside the body with elbows bent (approx. 70°) and positioned next to the trunk, with his hands holding the ski poles diagonally in relation to the ground and avoiding contact with it. In T3 (photo T3P1S1), it can be seen that the athlete maintains the same position of the arms with elbows bent (approx. 70°) as in the 1st campaign, but with his body trunk more perpendicular to the floor, causing the ski-tip to be more parallel to the ground.

*P1 – 20m/s* – In T2 (photo T2P1S2), the athlete reproduced the same position as at 10m/s but with the trunk and arms held slightly further back, affecting in turn the position of the forearms and hands. In T3 (photo T3P1S2), a slight extension of the neck and elevation of the skis in relation to the ground can be seen.

*P1 – 30m/s* – In T2 (photo T2P1S3), the athlete maintains his performance but with a subtle flexion of the neck, however, the position of the ski-tips are modified, increasing the frontal area of exposure. In T3 (photo T3P1S3), the athlete consistently reproduces his performance as at 20m/s, maintaining the principal points of reference.

**Figure 46: Position 1 – Neutral Position**

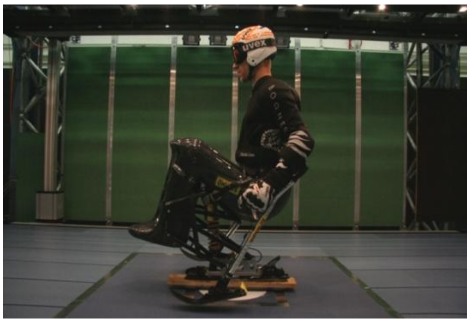



photo T2P1S1 – Drag Coeff. 0.395 **10 m/s** photo T3P1S1 – Drag Coeff. 0.381


photo T2P1S2 – Drag Coeff. 0.396 **20 m/s** photo T3P1S2 – Drag Coeff. 0.385


photo T2P1S3 – Drag Coeff. 0.401 **30 m/s** photo T3P1S3 – Drag Coeff. 0.399

*P2 – 10m/s* – For the second position in T2 (photo T2P2S1), the athlete assumed a forward flexion of the trunk (approx. 30º). Arms are along the body but slightly to the front, with elbows bent (approx. 80º) and positioned close to the body at the height of the thighs. As the forearms are more advanced the hands are closer to the legs. In T3 (photo T3P2S1), it can be seen that the trunk and elbows of the athlete have less forward flexion than in the 1$^{st}$ campaign, with the arms held slightly back and more elevated, and the hands by the legs with the ski-tips raised further from the ground.

*P2 – 20m/s* – In T2 (photo T2P2S2), the athlete reproduced a position almost equal to that assumed at 10 m/s. In T3 (photo T3P2S2), the athlete again reproduced a position almost equal to that assumed at 10m/s, except for a slight extension of the neck.

*P2 – 30m/s* – In T2 (photo T2P2S3), athlete reproduced a position almost equal to that assumed at 20m/s but with greater flexion of the neck, however, the angle of the ski-tips changed, increasing the frontal area of exposure. In T3 (photo T3P2S3), the athlete again reproduced a position almost equal to that assumed at 20m/s, but with a slight forward flexion of the neck.

**Figure 47: Position 2 – Run Position**


photo T2P2S1 – Drag Coeff. 0.393 **10 m/s** photo T3P2S1 – Drag Coeff. 0.401


photo T2P2S2 – Drag Coeff. 0.393 **20 m/s** photo T3P2S2 – Drag Coeff. 0.398


photo T2P2S3 – Drag Coeff. 0.407 **30 m/s** photo T3P2S3 – Drag Coeff. 0.408

*P3 – 10m/s* – For the third position in T2 (photo T2P3S1), the athlete adopted a position of maximum forward flexion of the trunk (approx. 40º) with arms almost perpendicular to the floor. His elbows were bent (approx. 70º) and positioned close to the body at the height of the legs. His forearms were further forward with the hands positioned well in front in relation to the line of the legs. In T3 (photo T3P3S1), it can be seen that the athlete assumed a maximum forward flexion of the trunk with elbows almost fully extended, arms oblique to the floor and the hands positioned to the front of the legs.

*P3 – 20m/s* – In T2 (photo T2P3S2), the athlete reproduced the desired position with a subtle elevation of the hands and consequently, the skis also. In T3 (photo T3P3S2), the athlete reproduced the position assumed for 10 m/s but bringing the chin closer to the knees, extending the elbows more and advancing the hands and ski-tips still further forward.

*P3 – 30m/s* – In T2 (photo T2P3S3), the athlete reproduced the position almost equal to that assumed at 20m/s but with the arms held a little further back. In T3 (photo T3P3S3), the athlete maintained his performance as at 20 m/s, looking to align the head with the spinal column.

**Figure 48: Position 3 – “Aggressive” Position**

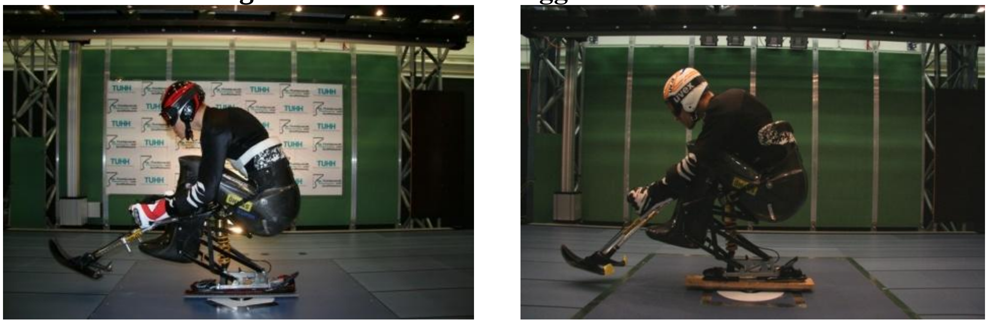


photo T2P3S1 – Drag Coeff. 0.300 **10 m/s** photo T3P3S1 – Drag Coeff. 0.244

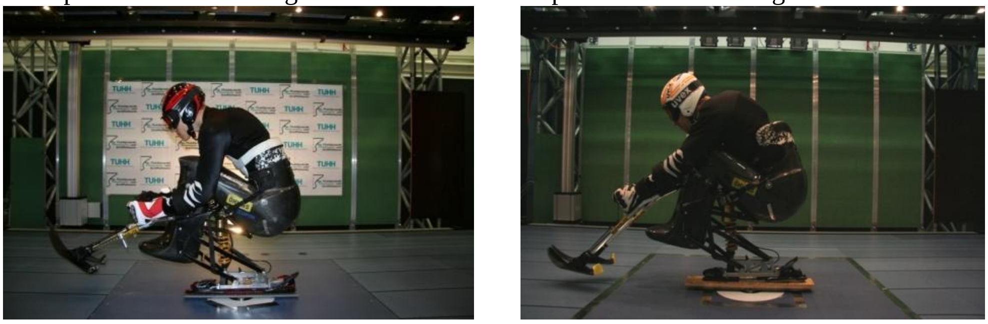


photo T2P3S2 – Drag Coeff. 0. 296 **20 m/s** photo T3P3S2 – Drag Coeff. 0.284

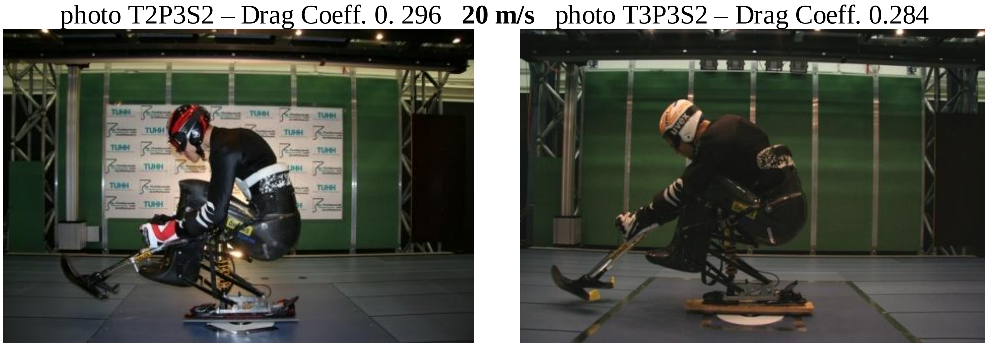


photo T2P3S3 – Drag Coeff. 0.303 **30 m/s** photo T3P3S3 – Drag Coeff. 0.283

*P4 – 10m/s* – For the fourth position in T2 (photo T2P4S1), the athlete assumed maximum forward flexion of the trunk (approx. 40º). The left arm assumes an intermediate pose between positions 3 and 4, whilst the right arm is placed in a new raised position with elbow bent (approx. 90º), thus raising the ski-outriggers to a position above the line of the horizon (positive angle of attack). In T3 (photo T3P4S1), the athlete’s head is more elevated and he has maximum forward flexion of the trunk, with the left arm alongside the trunk and the forearm oblique to the ground, maintaining the ski- outriggers at that same angle. As in the 1st campaign, the right elbow was bent (approx. 90º), raising the ski-pole to a position above the line of the horizon.

*P4 – 20m/s* – In T2 (photo T2P4S2), the athlete reproduced a position almost equal to that assumed at 10 m/s but lowering the left ski-tip, bringing it closer to the ground. In T3 (photo T3P4S2), the athlete reproduced a position almost equal to that assumed at 10 m/s for the principal points of reference (head, arms, trunk, forearms and hands), but moving the right ski pole a little further forward.

*P4 – 30m/s* – In T2 (photo T2P4S3), the athlete reproduced a position almost equal to that assumed at 20 m/s but with a subtle reduction in flexion of the trunk, and the ski-tip more angled. In T3 (photo T3P4S3), the athlete maintained his performance as at 20 m/s but with a slightly greater forward flexion of the trunk.

**Figure 49: Position 4 – Extra Position**

photo T2P4S1 – Drag Coeff. 0.251 **10 m/s** photo T3P4S1 – Drag Coeff. 0.306

photo T2P4S2 – Drag Coeff. 0.263 **20 m/s** photo T3P4S2 – Drag Coeff. 0.314

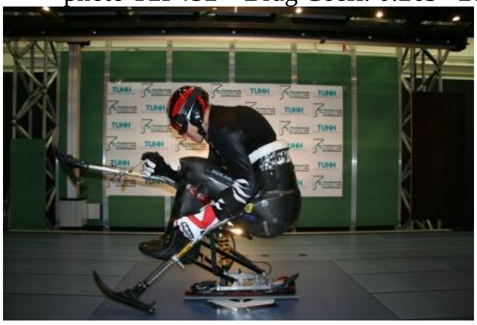


photo T2P4S3 – Drag Coeff. 0.296 **30 m/s** photo T3P4S3 – Drag Coeff. 0.322

### Frontal Photos Recorded after the WT Experiments

*P1 – No wind* – In T2, it can be seen from the photo (T2P1) that the athlete's head is aligned with the trunk and with the shoulders slightly uneven. His arms are held alongside the body, positioned fairly close to the trunk. Elbows and hands are slightly uneven whilst holding the ski-outriggers and preventing the ski-tips from coming into contact with the ground. The trunk was aligned with the monoski. In T3 (photo T3P1), C3 was able to reproduce the standard position but bringing the arms still closer to the trunk. This photo was the origin of the diagram (T3P1v2) used to calculate the area of the athlete complete with the monoski in P1.

**Figure 50: Position 1 – Neutral Position**

photo T2P1 photo T3P1 T3P1v2

*P2 – No wind* – In T2 it can be seen from the photo (T2P2), that the athlete remained with his head in alignment and with shoulders level. His arms are alongside the body and held slightly away from the trunk. Elbows and hands are kept level whilst holding the ski-outriggers and keeping the ski-tips elevated from the floor. The trunk is aligned with the monoski. In T3 (photo T3P2), it can be seen that the athlete reproduced the same posture as for the 1st campaign, but the arms are held closer still to the trunk. From the photo taken it was possible to produce the diagram (T3P2v2) and calculate the area of the athlete complete with monoski in P2.

**Figure 51: Position 2 – Run Position**

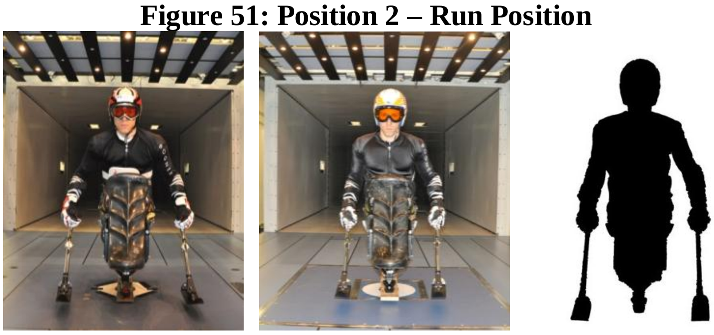


photo T2P2 photo T3P2 T3P2v2

*P3 – No wind* – In T2, it can be seen from the photo (T2P3) that the athlete's head was aligned with the monoski and that the shoulders were level. His arms were held alongside the body and close to the legs. Elbows and hands are kept level whilst holding the ski poles and the trunk is aligned with the monoski. In T3 (photo T3P3), a small difference in the execution of the position can be seen. The arms are held alongside the legs and the eyes more forward facing. From the photo taken it was possible to produce the diagram (T3P3v2) and calculate the area of the athlete complete with monoski in P3.

**Figure 52: Position 3 – "Aggressive" Position**

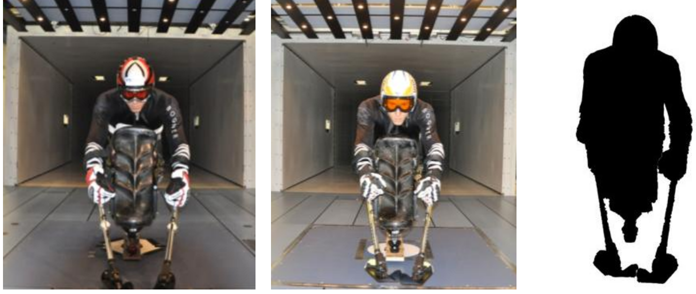


photo T2P3 photo T3P3 T3P3v2

*P4 – No wind* – In T2, it can be seen from the photo (T2P4) that the athlete was with his head aligned with the longitudinal axis and with shoulders level. His arms are held in different positions, with the left lower and close to the legs, whilst the right is at body level with the elbow bent and the hand close to the knees, maintaining the ski in front of the body. In T3 (photo T3P4), it can be seen that as in the previous positions, C3 manages to keep the body more compact. From the photo taken it was possible to produce the diagram (T3P4v2) and calculate the area of the athlete complete with monoski in P4.

**Figure 53: Position 4 – Extra Position**

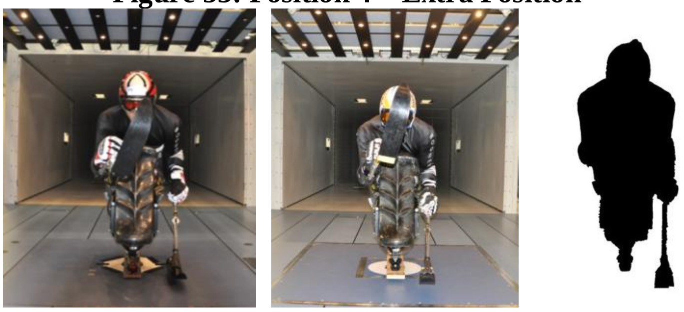


photo T2P4 photo T3P4 T3P4v2

The general results of the anthropometric evaluation, the treatment of the photographic records, and the questionnaires and field notes completed by the athletes for both campaigns have now been presented. We would now like to put forward, in addition to the individual results presented in relation to tests performed on the ergometric treadmill and bicycle, and in the wind tunnel, a follow-up of the individual analysis by means of a discussion for the athlete in question.

### 2.3.2 Human Performance - Discussion

**Objectives Assessment**

The evaluation process was conducted with the intention of increasing the range of information and understanding of the performance structure that affects the world of the athletes from the *DPS*. It also aimed to analyse and compare individual results, contrasting them with other team members and to eventually relate these to other Paralympic athletes (e.g. wheelchair sports).

This athlete, born in February 1985, is a relative newcomer to training with the *DPS* and did not participate in the 2010 Paralympic Winter Games in Vancouver. His conduct over the course of these experimental studies was exemplary and he presented interesting and respectable results for this competitive sport, as well as for the scientific community.

**Anthropometric Assessment**

From the anthropometric measurements taken, it was observed that C3 maintained his body weight of 63Kg during the period between the two evaluative campaigns. Consequently, his body mass index of 18.81kg/m$^2$ was unchanged and remained at the lower end of the range considered to be normal, according to "The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults" (National Institutes of Health, 2000).

The seated height (126.5cm) and arm-span (180cm) of the athlete were recorded in the 2$^{nd}$ campaign and it was possible to determine his trunk index (Cormic Index and Relative Arm-span) from this data. The Cormic Index calculated of 69.12 (macrocormic) for athlete C3 was the second highest value found among the sit-ski athletes taking part in the 2$^{nd}$ campaign, whilst his relative arm-span of 98.36 was the lowest recorded among the participants. In principle, this situation should present a disadvantage for the athlete for those events requiring constant changes of direction, since C3 has a longer seated (trunk-cephalic) height and shorter arms than the other athletes, this being the opposite situation to skier C2.

**Physiological Assessment**

The spiroergometry evaluation carried out to check the fitness condition of this athlete produced consistent and coherent results without exposing him to risk. The athlete can improve his aerobic and metabolic fitness and his performance accordingly, if he increases his upper body strength-endurance, especially of the trunk. This increase will give greater coordinative predisposition as he has difficulty in maintaining an upright posture, especially under conditions of load.

His performances in 2010 and 2011 were similar with a difference of only 1 minute between the two (Vinagre *et al*, 2012). In the 1st campaign he neared the end of the 3rd stage, whilst in the 2nd campaign he began the 4th stage, advancing 48s into it. He presented superior figures for both $FC_{max}$ and in recovery in 2011. It can be said that C3 continues to improve his physiological performance as, despite his 2011 $\dot{V}O_2$ reading being inferior in relation to 2010, he was able to continue the test for a longer time period. The $\dot{V}O_2$ values presented by C3 were 2380mL/min (37.77mL/kg/min) in the 1st campaign and 2251ml/min (35.73mL/kg/min) in the 2nd campaign. Although this test protocol differs from those adopted by other authors in their evaluations, as detailed by (Bhambhani, 2002) in Table 12, his results are comparable with them. It should be noted that the results encountered in Table 12 refer to trained and untrained individuals in wheelchair sports.

**Table 12 – Peak Aerobic Power in Trained and Untrained Male Wheelchair Athletes with Paraplegia**

| Study | Mode | n | ISMGF classification | Lesion | $VO_2$ (L/min) | $VO_2$ (ml/kg/min) | HR (beats/min) |
|---|---|---|---|---|---|---|---|
| **Trained** | | | | | | | |
| Bernard et al. | WERG | 7 WA | II, III | T1- T10 | 2.35 | 34.3 | 169 |
| Campbell et al. | WCT | 10 WA | | T2-L2 | 1.91 | | 196 |
| Cooper et al. | WERG | 11 WR | II-IV | T3-L1 | 2.46 | 37.4 | 186.5 |
| Hooker and Wells | ACE | 6 WR | II-IV | T4-T12i | 2.72 | 43.1 | 180.3 |
| Huonker et al. | WERG | 29 WA | II-V | T1-S2 | 2.42 | 34.5 | 183.3 |
| Price Campbell | ACE | 11 WA | | T3-4-L1 | 2.04 | 30.5 | 185 |
| Van der Woude et al. | WERG | 8 WA | | T3-L1 | 2.04 | 32.9 | |
| **Untrained** | | | | | | | |
| Raymond et al. | ACE | 10 UT | | T5-T12 | 1.81 | 26.3 | 175 |
| Huonker et al. | WERG | 20 UT | II-V | T1-S2 | 1.76 | 23.9 | 161.8 |

ACE – arm crank ergometer; i – incomplete lesion; ISMGF International Stoke Mandeville Games Federation functional classification; n – sample size; $VO_2$ - Oxygen Uptake; UT – untrained participants; WA – wheelchair athletes (mixed group of athletes); WCT – wheelchair mounted on treadmill; WERG – wheelchair ergometer. Table incomplete, taken from an article by Yagesh Bhambhani (2002).

In assessing the functional capacity of C3, we must look at the mechanical and physiological performance and the relationship between them (Wüpper, 2002). Athlete C3 was able to advance to the 3rd stage (60W) in experiment n.1 and continue there for 1min 48s. From a physiological perspective he was able to generate 867.66W, representing an efficiency of 6.92%. In experiment n.4, C3 was able to reach the 4th stage (80W) and continue there for 48s. From a physiological perspective he was able to generate 834.63W, representing an efficiency of 9.59%, which although better than for the 1st campaign, was still a lower figure when compared to the performance of his team colleague C1.

When comparing the HR reached with the maximum pre-determined HR according to the Karvonen formula (Robergs 2002, Policarpo 2004), the peak HR reached by this volunteer in the two evaluative campaigns was equivalent to submaximal HR in relation to the pre-determined $HR_{max.}$ Follow-up measurements for C3 taken 3 minutes after both tests were ended show that his HR remained a little over 140bpm (142bpm) for T1, whilst for T2 this figure had dropped to below 140bpm (123bpm). This indicates an increase in cardiovascular fitness, although still leaving room for further improvement. Table 12 verifies the results presented in these experiments, although the ages of those volunteers performing the tests are not included.

A difference in tested lactate concentrations for C3 occurred between the post-test recuperation periods for both campaigns. The response of the volunteer was much better in the second campaign, with the peak lactate figure recorded after test end being lower than the figure recorded for the first campaign, even after 5 minutes of the post-recovery period.

**Aerodynamic Evaluation**

The aerodynamics evaluation was intended to take account of the amount of drag produced by the athletes and it generated innovative results without exposing C3 to risk. The performance of C3 over the two campaigns was similar, although he was still able to improve his results from the first year to the second. He conducted his test in 2011 within the requested parameters and presented lower values for almost all positions, except for P4 where his performance was better in the first campaign. It is interesting to note that C3 performed P2 better than P1 in both campaigns, with the same happening with results for P4 in relation to P3, except for the first stage of the speed test. As can be seen in Table 11 and in Figures 39, 40, 41 and 42, the values obtained from the athlete in testing indicate a degree of inconsistency.

In a comparison of the results for **D** in 2011 with those of 2010, it can be seen that C3 was able to reduce the **D** produced by the posture offering most resistance (P1). It can also be stated that there was deterioration in the 2011 test performance of P4 in relation to 2010. In the other previously performed positions, the athlete always gave a better performance in 2011 than in 2010, as can be seen in Table 11 and Figures 42 and 43.

A greater consistency in the results can be seen in 2011 when comparing the $\mathbf{C_D}$ values between the two years, as an increase in $\mathbf{C_D}$ for each position carried out was found with the increase in wind speed. This did not occur in T2 for P3, when a decrease in the $\mathbf{C_D}$ presented by C3 happened when moving to the second stage (20m/s). Incorporating calculation of the $\mathbf{C_D}$ according to the frontal area of the individual in the 2$^{nd}$ campaign in 2011 brought with it even more accurate values. The figures for the **D Area** of C3 calculated from the frontal area at 30m/s represent 0.538m$^2$ in P1, 0.567m$^2$ in P2, 0.371m$^2$ in P3 and 0.349m$^2$ in P4.

**Postural Evaluation**

**Analysis of Lateral Photos**

In P1, both in 2010 and 2011, the volunteer was able to carry out and repeat the required posture with small alterations in trunk position. However, comparing the postures adopted in one campaign to the next, in 2010 fundamental differences can be seen in his head position (the face of C3 is further forward than the chest) and in the position of the outriggers, that change angle in the 3rd stage of the wind speed test. In contrast, in 2011, C3 maintains the alignment of his face and chest and the outriggers remain parallel to the ground for all 3 stages

In P2, it can be seen that both in 2010 and 2011 C3 showed consistency in his performance. When comparing postures between the two campaigns we can see that in 2010, C3 displayed greater forward flexion of the trunk than in 2011 and his eyes were also directed more to the ground.

In P3, it is observed that C3 produced a homogeneous performance in 2010, indicating that this posture is easier to maintain during the test and is well suited in terms of execution of the position. In 2011, there was little difference from one stage to another, with C3 just flexing his trunk slightly more forward from the 2nd stage onwards. Comparing his stance between the two campaigns, it can be seen that in addition to this minor adjustment of the trunk from the previous year, C3 also showed greater extension of the elbows in 2011, thus bringing his forearms, hands and ski-poles further forward in relation to his legs.

In P4, we can see that both in 2010 and 2011, despite the differing positions of holding the ski-poles, C3 could carry out and maintain the posture for the 3 stages with much precision, especially in the 1st campaign. When comparing postures from one year to the next, it can be seen that C3 opted to conduct the test in 2011 with a more "upright" stance, i.e., not bending over the legs to the maximum degree, and keeping the head raised so that eye direction is almost parallel to the ground.

**Analysis of frontal photos**

An analysis of the postures held by C2 in the frontal plane for the two campaigns demonstrates that in P1, the volunteer was able to carry out and repeat the posture with minimal alterations in the positioning of the arms. The same occurred for P2 and P3 in 2011, when he sought to keep the arms closer to the body. C3 was the first volunteer to have recorded P4 in both the campaigns. It can be seen from the diagrams created from P1, P2, P3, and P4 in experiment n. 3 only, that the frontal area of C3 generated by the different postures he assumed became increasingly smaller as the stages advanced.

**Questionnaires**

Questionnaires applied in the 2nd campaign only, provided more important information regarding the perception of discomfort through use of the Body Discomfort Diagram. C3 noted feeling moderate discomfort in the cervical region, a moderate/high level of discomfort in the scapula area, mainly to the right side (shoulder and arm), and moderate/mild discomfort to the lower limbs. An outline of the course of his training year was obtained. C3 trains on a daily basis throughout the year with two different training sessions being performed on some days. In the period from March to June, after the competitive season has ended, C3 completes 50% of his weekly physical work training with a mix of aerobic endurance and strength work. The other 50% of his time is dedicated to technical and tactical training and other sporting activities (e.g. wheelchair basketball). In the period from June to September, the proportion of physical work remains the same but more time from this 50% is focused on aerobic endurance (80%), with the strength training supplementing this physical preparation. The remaining 50% of time continues to be dedicated to technical and tactical activities and wheelchair basketball. In the period of Sept/October to December, he continues the work developed to date but increasing the emphasis on technical and strength work. The competitive season takes place in the months from Dec/January to March, with C3 doing his greatest volume of training and seeking to divide his load in such a way that he still dedicate 25% of his time to physical workouts and the remaining 75% to technical and tactical work and specific training.

His best results in the World Alpine Skiing Championships 2011 (Sestriere/ Italy), which took place between the two evaluation campaigns, was 6th place in the Giant Slalom race, a test that demands a high degree of manoeuvrability. It is important to point out that the season ended without him having suffered any accident or significant injury.

C3 indicated in the questionnaire that he feels uncomfortable after two straight hours spent in his wheelchair. In the replies related to the WT evaluation, it can be seen that C3 was able to safely and comfortably conduct the test, finding it to be relatively easy. He believes that the test results are not particularly important and does not know exactly how they can be incorporated into his performance and training routine. His completion of the post-test questionnaire confirmed what he had stated in the pre-test questionnaire, but added to the information that he feels the most enjoyable test position performed to be P1.

From responses related to the investigation conducted at the Physiology Laboratory, it can be seen that C3 was able to safely perform the test, although he observed that it was not very comfortable from a postural and respiratory point of view. C3 found the demands of the test to be relatively difficult and could not perform it for long. He believes these results to be more important than those found in the WT, in terms of his performance and training. He stated that his training had minimal adaptations, since few new things were added to the sessions. In the post-test questionnaire, C3 confirmed his statements made pre-test, believing that the investigation in the 2nd campaign had been difficult, although acceptable.

### 2.4 Case number 4/ Volunteer (C4)

The fourth case is an athlete from the male alpine ski team, born on 19/01/81, and having a disability classification of LW12-1 in the sitting skiers (monoskiers) category. He suffered a skiing accident in 2006 injuring the spinal cord at the level of the second lumbar vertebra (L2), causing him incomplete paraplegia. His condition is considered to be mild, partially preventing movement of his legs. He began to monoski in 2008 and from the April he became a member of the *DPS*. As a new member of the team, he is still in an early developmental process to improve results within the sport.

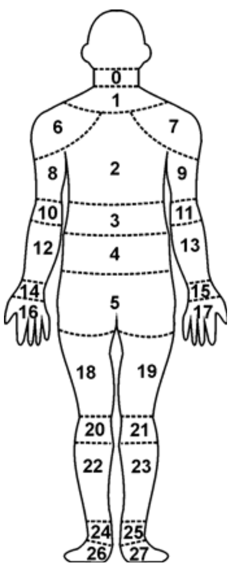
As can be seen from Tables I and II (p.78), C4 is 185cm tall and weighed 73kg at his last evaluation, giving him a Body Mass Index of 21.33 kg/m$^2$. Measurements of seated height and arm-span of the participant were also taken during the latter evaluative campaign, which allowed his Cormic Index and relative arm-span to be determined. The individual assessment of C3 also included important information related to his perceived discomfort through use of the Body Discomfort Diagram presented in Figure 54.

**Figure 54: Body Discomfort Diagram**

**Body Discomfort Diagram**

**1. No discomfort**
**2. Some discomfort**
**3. Moderate discomfort**
**4. High discomfort**
**5. Unbearable discomfort**

| | |
|---|---|
| 0. Neck | 1 2 3 4 5 |
| 1. Cervical | 1 2 3 4 5 |
| 2. High back | 1 2 3 4 5 |
| 3. Midle back | 1 2 3 4 5 |
| 4. Low back | 1 2 3 4 5 |
| 5. Hip | 1 2 3 4 5 |
| 6. R. Shoulder | 1 2 3 4 5 |
| 7. L. Shoulder | 1 2 3 4 5 |
| 8. R. Arm | 1 2 3 4 5 |
| 9. L. Arm | 1 2 3 4 5 |
| 10. R. Elbow | 1 2 3 4 5 |
| 11. L. Elbow | 1 2 3 4 5 |
| 12. R. Forearm | 1 2 3 4 5 |
| 13. L. Forearm | 1 2 3 4 5 |
| 14. R. Wrist | 1 2 3 4 5 |
| 15. L. Wrist | 1 2 3 4 5 |
| 16. R. Hand | 1 2 3 4 5 |
| 17. L. Hand | 1 2 3 4 5 |
| 18. R. Thigh | 1 2 3 4 5 |
| 19. L. Thigh | 1 2 3 4 5 |
| 20. R. Knee | 1 2 3 4 5 |
| 21. L. Knee | 1 2 3 4 5 |
| 22. R. Leg | 1 2 3 4 5 |
| 23. L. Leg | 1 2 3 4 5 |
| 24. R. Ankle | 1 2 3 4 5 |
| 25. L. Ankle | 1 2 3 4 5 |
| 26. R. Foot | 1 2 3 4 5 |
| 27. L. Foot | 1 2 3 4 5 |




According to Corlett and Wilson, 1986

### 2.4.1 Tests

In the first campaign, C4 was to be the fourth volunteer to conduct the ergometric treadmill test, however, in light of his results from the pre-test, he was not able to carry on to the evaluation procedure. He was the sixth volunteer to complete the wind tunnel testing. C4 was able to perform the ergometric test for the second campaign, and was the third in order to complete both this test and that of the wind-tunnel. C4 had not previously taken part in this type of evaluative campaign involving spiroergometry, but was able to follow the standard protocol and to prolong his performance as much as possible. The athlete was also unfamiliar with the wind tunnel testing carried out in tests 2 and 3, but was able to follow the standard protocol and complete all of the pre-planned steps.

**Cardiopulmonary Test**

**Preparations/ Control/ Immediately before/ During /After the test /Recovery**

The initial load encountered for T4 was 10.35N. The blood sample taken prior to the test showed a lactic acid concentration of 1.0mmol/L. The cardiac electrical activity of the volunteer was monitored closely during testing, together with the consistency of the recorded physiological values to ensure that none of the monitored recordings showed any warnings signs. The test session was brought to an end at the request of the athlete, having reached his limit of endurance. New blood samples were collected immediately at test end, and again 3min. and 5min. after the end, with these values being presented in Table 13. After removal of the mouthpiece/mask, the participant was asked about the nature and intensity of the limiting symptoms, with the replies being recorded on a standard form. Routine post-tests were conducted during the recovery period to ensure that both ECG and systemic blood pressure measurements returned to normal before the release of the volunteer, and the official ending of the test session.

**Results of Cardiopulmonary Test 4**

The volunteer successfully passed the pre-test for the second evaluative campaign and was authorised to take part in the actual testing session. The readings for $\dot{V}O_2$, HR and load values obtained from the spiroergometry are listed in Table 13 and in Figures 55, 56 and 57. The procedure began from the second load stage (40W) due to the resistance offered by the wheelchair and the load necessary to find the initial equilibrium point for the test.

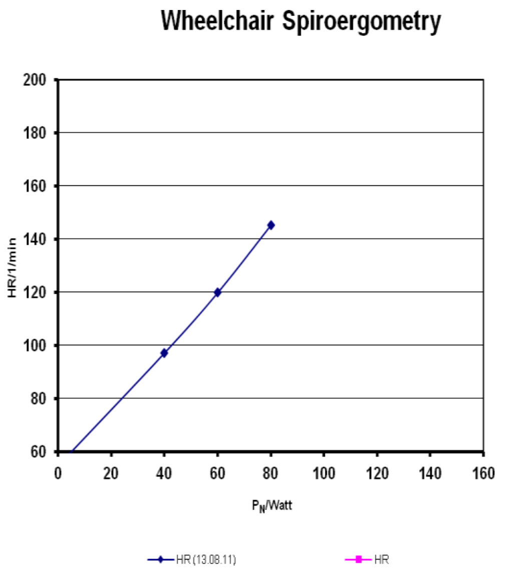
**Table 13 – Results of Test 4 for Athlete C4**

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 55 | 343 | 0.886 | 117.41 | 0.00 | 1.0 |
| 3 | 40 | 97 | 1647 | 1.067 | 589.70 | 6.78 | |
| 3 | 60 | 120 | 2264 | 1.121 | 821.01 | 7.31 | |
| 2min. 28s | 80 | 145 | 2886 | 1.234 | 1074.41 | 7.45 | |
| | | | | | | | |
| after Stop | | 149 | | | | | 9.6 |
| 1 | | 124 | | | | | |
| 2 | | 93 | | | | | |
| 3 | | 77 | | | | | 10.4 |
| 4 | | 74 | | | | | |
| 5 | | 73 | | | | | 11.0 |

$P_N$ – Mechanical output, HR - Heart Rate, $VO_2$ - Oxygen Consumption, RQ - Respiratory Quotient, $P_B$ Gross output, e - equivalent $P_{N/}$ $P_B$, LA – Lactate.

In the second campaign, C4 was able to carry out the test with different loads in accordance with the protocol. From a biomechanical outlook, he was able to maintain an almost constant frequency of arm propulsion as the test phases advanced, presenting long “strokes” with a regular rate per minute. The frequency of his arm propulsion for the 1$^{st}$ stage was 65 strokes/min, with the 2$^{nd}$ stage being 66 strokes/min, the 3$^{rd}$ stage being 68 strokes/min. and the 4$^{th}$ stage being 70 strokes/ min. The highest load achieved by the athlete in the test was 80W, reached during the fourth stage. He presented a $\dot{V}O_2$ of 2886 ml/min and a lactate level of 9.6mmol/L immediately after the test end. The maximum HR achieved was 149bpm, measured immediately after the test and presented in Table 13.

**Figures 55, 56 and 57 – Results of Spiroergometry (test 4) for athlete C4**



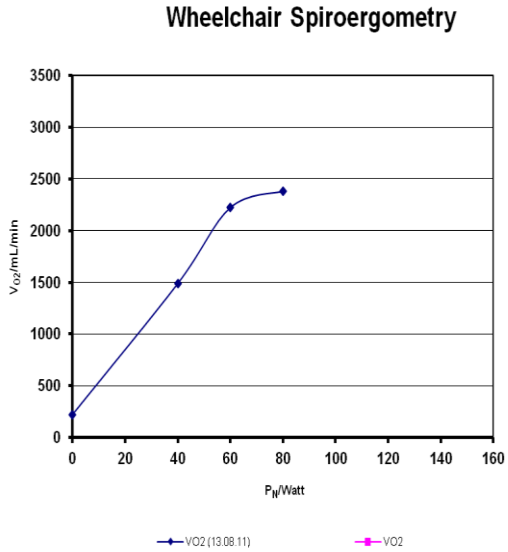




**Figure 55:** HR performance curve in relation to stage of testing, conducted in 2011
**Figure 56:** $\dot{V}O_2$ performance curve in relation to stage of testing, conducted in 2011.

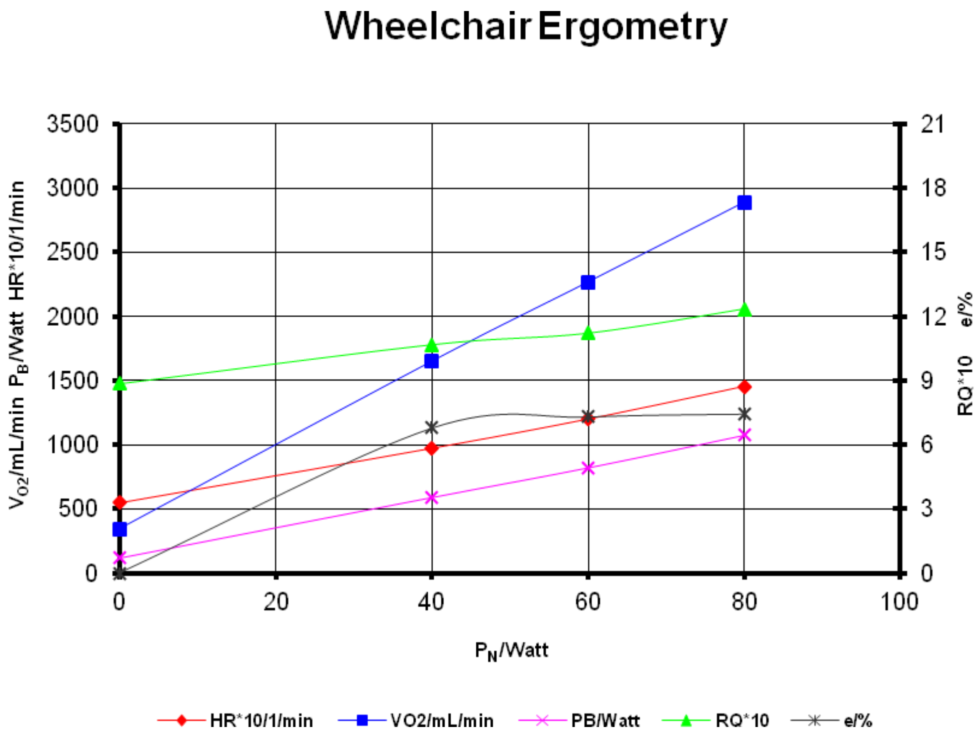



**Figure 57 –** Physiological data recorded during Test 4 in 2011
Performance curves for HR, $\dot{V}O_2$, $P_B$, RQ and "e", respectively.

A fluctuation occurred with respect to the lactate levels found during the post-test recuperation period for C4. The regenerative response of the volunteer was slow, with the peak lactate concentration registered at the test end being surpassed by the subsequent measurements. It can be argued that the response of the volunteer was worse than his team colleagues as his performance was neither the longest nor the most efficient (figure 58).

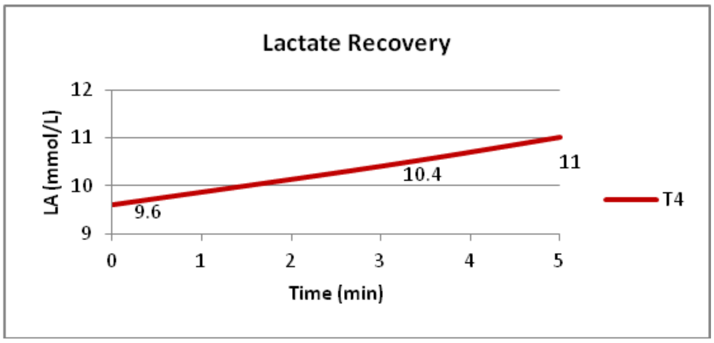


**Figure 58 –** Physiological data (lactate) after Test 4 conducted in 2011.

### Aerodynamic Test

**Preparations; Control; Immediately before, During, After the test; Recovery**

The volunteer was monitored closely during testing in relation to both his personal safety and his performance of the test positions to be carried out. No contact occurred during testing between the support platform for the monoski and the WT floor. C4 consistently performed and repeated every position requested of him, showing no signs of fatigue during testing. The consistency of the force values together with the respective photographic records for the evaluated settings, were also ensured.

The endpoint for both tests was carried out by the technical team who were responsible for control management of the WT system and for the timing of photographic records for each position performed, as well as the interval between changes of velocity and position. The athlete voiced no complaints when asked about his experience of the nature and intensity of this evaluation method after completion of the test. Spontaneous comments made by the athlete during T2 were recorded in field notes, and a questionnaire was applied both before and after the evaluation for T3.

**Table 14 – Wind Tunnel Test Data for C4**

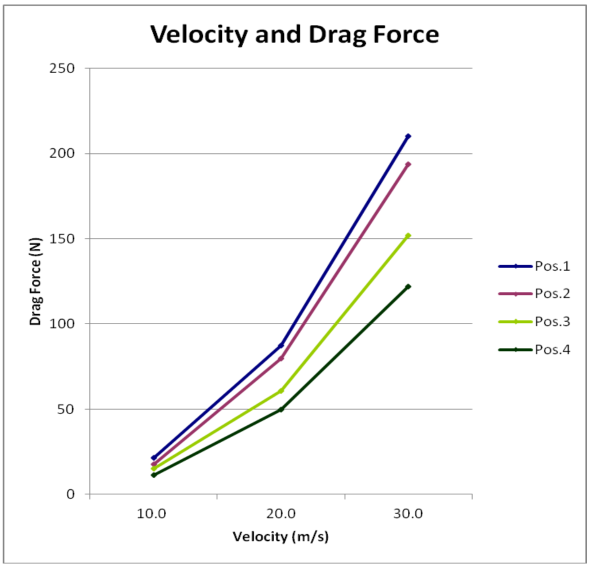
| **Pos.** | **Velocity [m/s]** | **$C_D$ [-]** | **$C_D$ [-]** | **Area [m$^2$]** | **$C_D$ v2 [-]** | **D Area [m$^2$]** | **Drag Force [N]** | **Drag Force [N]** |
|---|---|---|---|---|---|---|---|---|
| | | **2010** | **2011** | **2011** | **2011** | **2011** | **2010** | **2011** |
| Ref. | | | | | | | | |
| 1 | 10.0 | (0.735) 0.367 | **0.383** | 1.3412 | 0.2856 | 0.513 | 21.65 | 21.41 |
| | 20.0 | (0.741) 0.370 | 0.369 | 1.3412 | 0.2755 | 0.494 | 87.19 | 84.45 |
| | 30.0 | **(0.794) 0.397** | 0.360 | 1.3412 | 0.2682 | 0.482 | **210.08** | 187.38 |
| Ref. | | | | | | | | |
| 2 | 10.0 | (0.599) 0.299 | 0.361 | 1.3571 | 0.2658 | 0.489 | 17.65 | 20.18 |
| | 20.0 | (0.679) 0.339 | 0.352 | 1.3571 | 0.2590 | 0.477 | 79.86 | 80.37 |
| | 30.0 | (0.733) 0.366 | 0.364 | 1.3571 | 0.2681 | 0.493 | 193.81 | **189.61** |
| Ref. | | | | | | | | |
| 3 | 10.0 | (0.509) 0.254 | 0.250 | 1.3202 | 0.1891 | 0.330 | 14.96 | 13.96 |
| | 20.0 | (0.518) 0.211 | 0.239 | 1.3202 | 0.1809 | 0.315 | 60.90 | 54.59 |
| | 30.0 | (0.575) 0.230 | 0.240 | 1.3202 | 0.1820 | 0.316 | 152.03 | 125.22 |
| Ref. | | | | | | | | |
| 4 | 10.0 | **(0.381)** 0.190 | 0.231 | 1.2758 | 0.1814 | 0.294 | **11.24** | **12.94** |
| | 20.0 | (0.422) 0.211 | 0.226 | 1.2758 | 0.1768 | 0.288 | 49.60 | 51.56 |
| | 30.0 | (0.461) 0.230 | **0.221** | 1.2758 | 0.1736 | 0.281 | 122.04 | 115.41 |

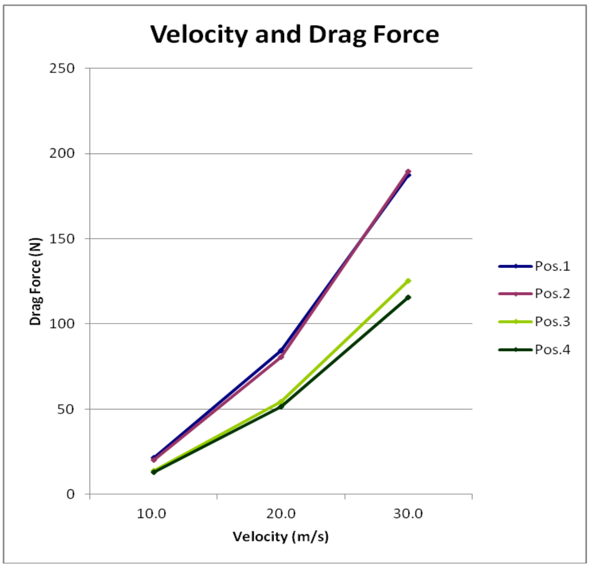
Obs.: The values were obtained from the estimated frontal area of 0.5m$^2$ of the athlete in 2010 and 1m$^2$ in the 2011 test. The numbers highlighted in bold are the maximum and minimum values found in each session. The colours green and orange represent an improvement or deterioration in performance, respectively. The blue represents the values found for the CD from experiment 3 for the new values calculated of the frontal area based on the technique of counting pixels of digital photographs.

**Results of Aerodynamics Tests 2 and 3**

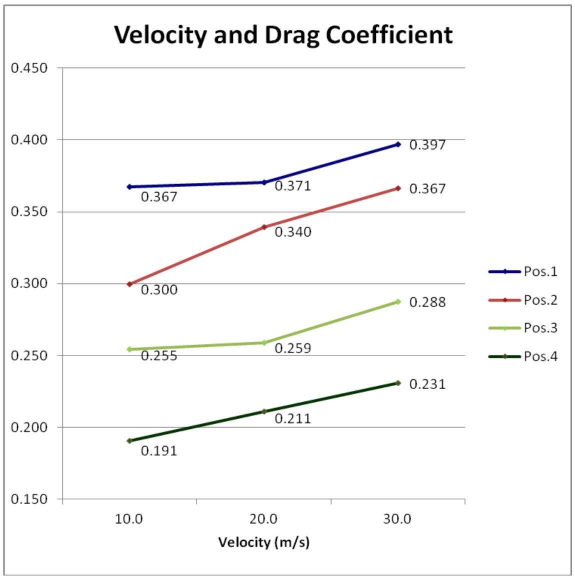
C4 was able to complete both the WT tests in accordance with the outlined protocol, as can be seen in Table 14 and in figures 59, 60, 61 and 62. In terms of coordination, he was also able to perform, maintain and repeat the requested positions with much precision. The largest **D** presented by him was 210.08N for T2 in P1 at 30m/s, whilst for T3 this value was 189.61N in P2 at 30m/s. The lowest **D** value presented by him for both tests was 11.24N for T2 and 12.94N for T3, both whilst adopting P4 at 10m/s. The largest $\mathbf{C_D}$ presented by him was 0.794 (0.397) for T2 in P1 at 30 m/s, whilst for T3 this value was 0.383 in P1 at 10 m/s. His lowest $\mathbf{C_D}$ value for T2 was 0.381 (0.190) in P4 at 10 m/s, and for T3 this value was 0.221 in P4 at 30 m/s.

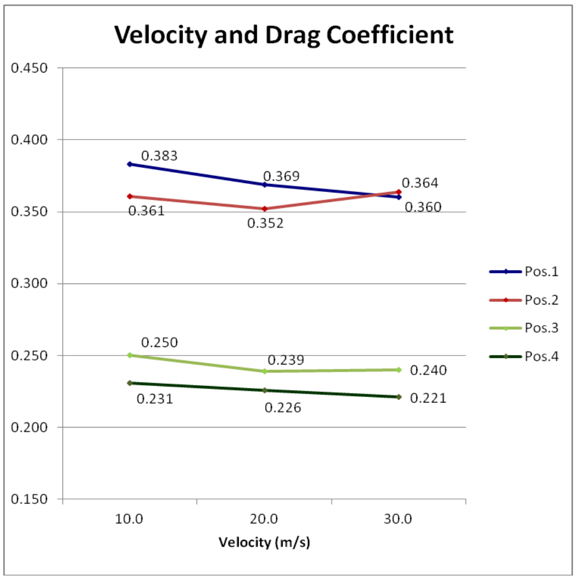
It can be seen from the photographic records that follow that the values presented with respect to each photo have already been corrected, enabling a direct comparison to be made. Similarly, these values were also used in the construction of comparative graphs between each campaign and configuration performed.




**Figures 59 and 60 –** Performance curves for **D** according to test stages performed in 2010 and 2011.




**Figures 61 and 62 –** Performance curves for **CD** according to test stages performed in 2010 and 2011.

**Description of Positions**

**Lateral Photos Recorded in the WT Experiments**

*P1 – 10 m/s* – In the T2 (photo T2P1S1), the athlete presented with his trunk perpendicular to the ground. His arms are held slightly back with elbows bent (approx. 60º), positioned next to the trunk, with his hands holding the ski poles diagonally in relation to the ground and avoiding contact with it. In the T3 (photo T3P1S1), it can be seen that the athlete maintained the same trunk position, when compared to the T2. His arms are held slightly further back, causing the ski poles to be raised further from the ground.

*P1 – 20 m/s* – In the T2 (photo T2P1S2), the athlete reproduced the same position as at 10m/s but with a slight extension of the neck and arms a little further back. In the T3 (photo T3P1S2), it can be seen that the athlete maintained the standard position but with a subtle alteration in the position of the ski-tips in relation to the ground.

*P1 – 30 m/s* – In the T2 (photo T2P1S3), the athlete maintained his performance but with a subtle advance of the arms. In the T3 (photo T3P1S3), the athlete had slightly greater forward flexion of the neck and the positioning of the elbows caused the arms to be held further back in relation to both the previous performances. The ski position also altered, increasing the frontal area of exposure.

**Figure 63: Position 1 – Neutral Position**


photo T2P1S1 – Drag Coeff. 0.735 **10 m/s** photo T3P1S1 – Drag Coeff. 0.383


photo T2P1S2 – Drag Coeff. 0.741 **20 m/s** photo T3P1S2 – Drag Coeff. 0.369


photo T2P1S3 – Drag Coeff. 0.794 **30 m/s** photo T3P1S3 – Drag Coeff. 0.360

*P2 – 10 m/s* – For the second position in the T2 (photo T2P2S1), the athlete assumed a forward flexion of the trunk (approx. 10º). Arms are held next to the body but to the front, with elbows bent (approx. 60º) and positioned close to the body at the height of the thighs. The hands are closer to the legs due to the forearms being further forward. In the T3 (photo T3P2S1), it can be seen that the trunk and elbows are bent to a greater degree than in the T2 with the arms held slightly further back and more elevated, and the hands held between the legs and thighs, keeping the skis more elevated from the floor.

*P2 – 20 m/s* – In the T2 (photo T2P2S2), the athlete reproduced a trunk position almost equal to that assumed at 10 m/s, with the main differences being arms held a little further back and elbows bent slightly more. In the T3 (photo T3P2S2), the athlete reproduced a position almost equal to that assumed at 10 m/s, other than the arms being a little setback and the head a bit more advanced.

*P2 – 30 m/s* – In the T2 (photo T2P2S3), the athlete reproduced a position almost equal to that assumed at 20m/s, however, the angle of the ski-tips changed, increasing the frontal area of exposure. In the T3 (photo T3P2S3), the athlete again reproduced a position almost equal to that assumed at 20m/s, but with a greater flexion of the elbows. The positions of the ski-tips are clearly modified.

**Figure 64: Position 2 – Run Position**

photo T2P2S1 – Drag Coeff. 0.599 **10 m/s** photo T3P1S1 – Drag Coeff. 0.361

photo T2P2S2 – Drag Coeff. 0.679 **20 m/s** photo T3P2S2 – Drag Coeff. 0.352

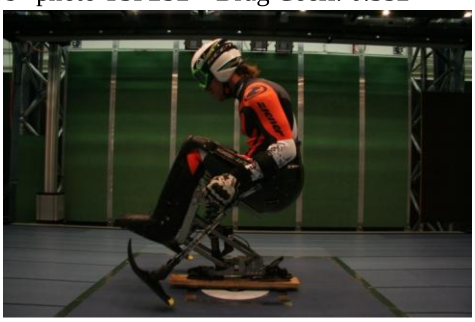
 

photo T2P2S3 – Drag Coeff. 0.733 **30 m/s** photo T3P2S3 – Drag Coeff. 0.364

*P3 – 10 m/s* – For the third position in the T2 (photo T2P3S1), the athlete adopted a position of forward flexion of the trunk (approx. 40º). His arms are held diagonally to the floor, elbows extended and positioned next to the body at the height of the knees. His forearms are further forward with the hands positioned well in front in relation to the line of the legs. In the T3 (photo T3P3S1), it can be seen that the athlete again assumes a forward flexion of the trunk (approx. 40º), with his elbows fully extended, arms diagonal to the floor and hands positioned to the front of the legs.

*P3 – 20 m/s* – In the T2 (photo T2P3S2), the athlete reproduced the desired position but with a subtle elevation of the hands and consequently, the skis also. In the T3 (photo T3P3S2), the athlete reproduced the position almost equal to that assumed at 10 m/s but with a subtle difference in head position bringing the face pointing more to the front. The skis were held slightly wider apart in both experiments for this position.

*P3 – 30 m/s* – In the T2 (photo T2P3S3), the athlete reproduced the desired position with a greater curvature of the back but with arms held in the same manner. In the T3 (photo T3P3S3), the athlete repeated his performance as at 10 m/s, however, an alteration of the position of the ski-tips is evident.

**Figure 65: Position 3 – "Aggressive" Position**


photo T2P3S1 – Drag Coeff. 0.509 **10 m/s** photo T3P3S1 – Drag Coeff. 0.250


photo T2P3S2 – Drag Coeff. 0.518 **20 m/s** photo T3P3S2 – Drag Coeff. 0.239


photo T2P3S3 – Drag Coeff. 0.575 **30 m/s** photo T3P3S3 – Drag Coeff. 0.240

*P4 – 10 m/s* – For the fourth position in the T2 (photo T2P4S1), the athlete assumed maximum forward flexion of the trunk (approx. 45º). The arms are held diagonally to the floor and the elbows extended, advancing the ski-poles well to the front. In the T3 (photo T3P4S1), the athlete again assumed maximum forward flexion of the trunk, with the left arm almost parallel to the floor, extending the ski-pole forward to its furthest point yet, whilst the right arm was held low. C4 assumed a more elevated head position for this campaign.

*P4 – 20 m/s* – In the T2 (photo T3P4S2), the athlete reproduced a position almost equal to that assumed at 10 m/s, but lowering the arms and skis, bringing them a little closer to the ground. In the T3 (photo E2P4S2), the athlete reproduced a position almost equal to that assumed at 10 m/s for the principal points of reference (head, arms, trunk, forearms and hands).

*P4 – 30 m/s* – In the T2 (photo T2P4S3), the athlete reproduced a position almost equal to that assumed at 20 m/s but with a subtle difference in head position. In the T3 (photo T3P4S3), C4 maintained his performance as at 20 m/s with the only alteration of note being the position of the ski.

**Figure 66: Position 4 – Extra Position**


photo T2P4S1 – Drag Coeff. 0.381 **10 m/s** photo T3P4S1 – Drag Coeff. 0.231


photo T2P4S2 – Drag Coeff. 0.422 **20 m/s** photo T3P4S2 – Drag Coeff. 0.226


photo T2P4S3 – Drag Coeff. 0.461 **30 m/s** photo T3P4S3 – Drag Coeff. 0.221

**Frontal Photos Recorded in the WT Experiments**

*P1 – No wind* – In the 1st exp., it can be seen from the photo (T2P1) that the athlete’s head was slightly rotated to the left, but with the trunk aligned and the shoulders level. His arms are held alongside the body, positioned next to the trunk. Elbows and hands are level whilst holding the ski poles and preventing the ski-tips from coming into contact with the ground. In the 2nd exp. (photo T3P1), C4 was able to reproduce the standard position but keeping the arms a little further away from the trunk. This photo was the origin of the diagram (T3P1v2) used to calculate the area of the athlete complete with the monoski in P1.

**Figure 67: Position 1 – Neutral Position**

photo T2P1 photo T3P1 T3P1v2

*P2 – No wind* – In the 1st exp., as can be seen from the photo (T2P2), the athlete presented with his head in alignment and with shoulders level. His arms are alongside the trunk and held to the front of it. The trunk is aligned with the monoski and elbows and hands level whilst securing the *ski poles* and keeping the ski-tips elevated from the floor. In the 2nd exp. (photo T3P2), it can be seen that the posture of the athlete does not lean as far forward as in the 1st campaign, however, the trunk is kept aligned and the shoulders, elbows and hands continue to be level. It was possible to generate the diagram (T3P2v2) from the photo taken and calculate the area of the athlete complete with monoski in P2.

**Figure 68: Position 2 – Run Position**

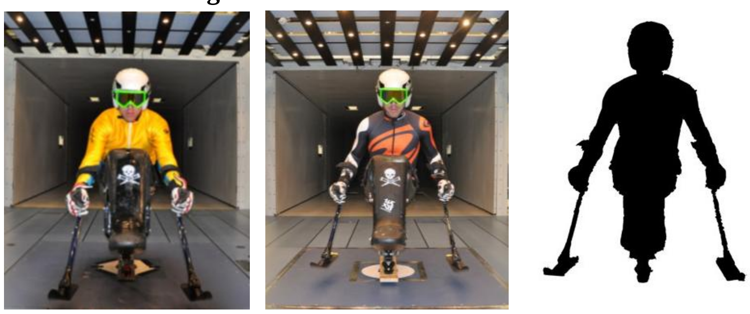


photo T2P2 photo T3P2 T3P2v2

*P3 – No wind* – In the 1st exp., it can be seen from the photo (T2P3) that the athlete's head was aligned with the monoski and that the shoulders were level. His arms are extended alongside and close to the legs. Elbows and hands are kept level whilst holding the *ski poles* and the trunk is aligned with the monoski. In the 2nd exp. (photo T3P3), a difference in the execution of the position can be seen with the arms further away from the legs and the head slightly rotated to the right. From the photo taken it was possible to produce the diagram (T3P3v2) and calculate the area of the athlete complete with monoski in P3.

**Figure 69: Position 3 – "Aggressive" Position**

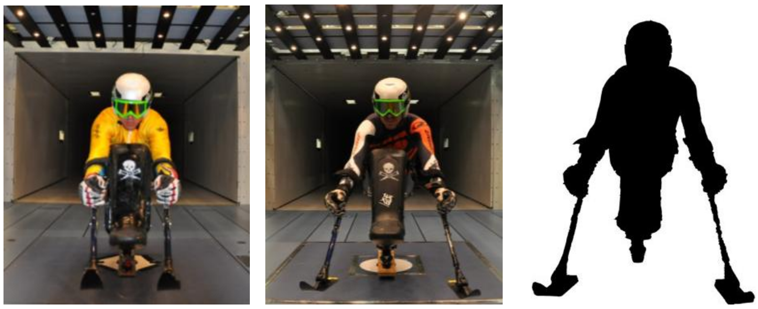


photo T2P3 photo T3P3 T3P3v2

*P4 – No wind* – In the 1st exp., it can be seen from the photo (T2P4) that the athlete was with his head aligned with the longitudinal axis and with shoulders level. His arms are held in different positions, with the left lower and close to the legs, whilst the right is held together with the body with elbow extended and hand close to the knees, maintaining the ski in front of the body. In the 2nd exp. (photo T3P4), it can be seen that the body of the athlete is slightly out of equilibrium. His arms are held in different positions with the right being lower and away from the legs, whilst the left is held next to the body with elbow extended, and the hand maintaining the ski to the front of the of the body. It was possible to generate the diagram (T3P2v2) from the photo taken and calculate the area of the athlete complete with monoski in P4.

**Figure 70: Position 4 – Extra Position**

photo T2P4 photo T3P4 T3P4v2

The general results of the anthropometric evaluation, the treatment of the photographic records, and the questionnaires and field notes completed by the athlete for both campaigns have now been presented. We would now like to put forward, in addition to the individual results presented in relation to tests performed on the ergometric treadmill, and in the wind tunnel, a follow-up of the individual analysis by means of a discussion for the athlete in question.

### 2.4.2 Human Performance - Discussion

**Objectives Assessment**

The evaluation process was conducted with the intention of increasing the range of information and understanding of the performance structure that affects the world of the athletes from the DPS team. It also aimed to analyse and compare individual results, contrasting them with other team members and to eventually relate these to other Paralympic athletes (e.g. wheelchair sports).

This athlete, born in January 1981, with a recent history of training with the *DPS*, participated in the 2010 Paralympic Winter Games in Vancouver and performed well, although not winning any medals. During the course of these experimental studies some situations occurred that made it unfeasible to collect the required data. In T1, for example, it was not possible for the athlete to conduct the test because the pre-test examination found him to have a cold. Another unique situation occurred with C4 in the WT tests, whereby the athlete used different equipment and did not carry out the same posture for one of the positions. This in fact constitutes a different comparative situation and can be considered unexpected but also interesting for the researchers involved in the study.

**Anthropometric Assessment**

From the anthropometric measurements taken, it was observed that C4 maintained his body weight of 73Kg and body mass index of 21.33kg/m$^2$ during the period between the two evaluative campaigns, remaining at the lower end of the range considered to be normal, according to "The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults" (National Institutes of Health, 2000).

The seated height (125cm) and arm-span (185cm) of C4 were recorded in the 2$^{nd}$ campaign and it was possible to determine his trunk index (Cormic Index and Relative Arm-span) from this data. The Cormic Index calculated of 67.56 (macrocormic) for athlete C4 was the least value found among the male sit-ski athletes taking part in the 2$^{nd}$ campaign, whilst his relative arm-span of 100 constitutes an average or neutral measurement for a sit-skier. This gives him a good arm-span that can be useful in those races requiring constant changes of direction, but also brings aerodynamic disadvantages for his performance due to a longer seated (trunk-cephalic) height.

**Physiological Assessment**

The spiroergometry evaluation carried out to check the fitness condition of this athlete produced consistent and coherent results without exposing him to risk. In comparison to his team colleagues, his performance in 2011 can be considered as average, in as much as he continued his test until the 4$^{th}$ stage (80W) during 8'28s and presented a $HR_{max}$ of 149bpm. It can be said that C4 is fully developing his cardiorespiratory capacity. The athlete can improve his aerobic and metabolic condition and consequently his performance if he improves his handling coordination of the WC, as well as knowing how to better administer the test under conditions of load. The $\dot{V}O_2$ values presented by C4 in T4 (2886ml/min - 39.53 ml/kg/min) was the highest $\dot{V}O_2$ of the *DPS*, however, his efficiency was low when compared to the test results for athletes C1 and C5. Although this test protocol differs from those adopted by other authors in their evaluations, as detailed by Bhambhani (2002) in Table 18, his results are comparable with them. It should be noted that the results encountered in Table 18 refer to trained and untrained individuals in wheelchair sports.

**Table 15 – Peak Aerobic Power in Trained and Untrained Male Wheelchair Athletes with Paraplegia**

| Study | Mode | n | ISMGF classification | Lesion | $VO_2$ (L/min) | $VO_2$ (ml/kg/min) | HR (beats/min) |
|---|---|---|---|---|---|---|---|
| **Trained** | | | | | | | |
| Bernard et al. | WERG | 6 WA | IV | T11-L3 | 1.79 | 28.5 | 183 |
| Campbell et al. | WCT | 10 WA | | T2-L2 | 1.91 | | 196 |
| Gass and Camp | WCT | 6 WR | III-IV | T10-L3 | 2.86 | 47.5 | 190 |
| Huonker et al. | WERG | 29 WA | II-V | T1-S2 | 2.42 | 34.5 | 183.3 |
| | WERG | 23 WA | | T6-S1, polio, spina bifida | 2.29 | 38.1 | |
| Veeger et al. | WCT | 13 WA | IV | T11-L3 | 2.42 | 36.9 | 182 |
| Vinet et al. | WCT | 8 WA | III-V | T8-L5 | 2.67 | 40.6 | 174 |
| **Untrained** | | | | | | | |
| Janssen et al. | WCT | 12 UT | IV | | 2.03 | 25.7 | |
| Huonker et al. | WERG | 20 UT | II-V | T1-S2 | 1.76 | 23.9 | 161.8 |

ACE – arm crank ergometer; i – incomplete lesion; ISMGF International Stoke Mandeville Games Federation functional classification; n – sample size; $VO_2$ - Oxygen Uptake; UT – untrained participants; WA – wheelchair athletes (mixed group of athletes); WCT – wheelchair mounted on treadmill; WERG – wheelchair ergometer. Table incomplete, taken from an article by Yagesh Bhambhani (2002).

In assessing the functional capacity of C4, we must look at the mechanical and physiological performance and the relationship between them (Wüpper, 2002). Athlete C4 was able to advance to the 4th stage (80W) in T4 and continue there for 2'28s. From a physiological perspective he was able to generate 1074.41W, representing an efficiency of 7.45%. The values found using the upper limbs in testing are lower than those found in tests performed with the lower limbs, as can be seen by comparing the results presented by C6 who conducted his test on an ergometric bicycle

When comparing the HR reached with the maximum pre-determined HR according to the Karvonen formula (Robergs 2002, Policarpo 2004), the peak HR reached by this volunteer in the evaluation was less than the submaximal HR in relation to the pre-determined $HR_{max}$. It can be seen that 3 minutes after the end of T1 his HR was found to be well below 140bpm (77bpm), indicating that the potential to improve his performance exists. Table 18 verifies the results presented in these experiments, although the ages of those volunteers performing the tests are not included.

**Aerodynamic Evaluation**

The aerodynamics evaluation was intended to take account of the amount of drag produced by the athletes and generated innovative results without exposing C4 to risk. His performance over the two campaigns was very similar with C4 presenting naturally irregular results, but he was still able to improve his marks in P1 and P3 and the last stage of P2 and P4 in the 2011 evaluation. As can be seen in Table 14 and in Figures 59, 60, 61 and 62, the values obtained in the 1st campaign are fairly consistent whilst the 2nd campaign showed some inconsistency.

In a comparison of the results for **D** in 2011 with those of 2010, it can be seen that C2 was able to reduce the **D** produced by the posture offering the most resistance (P1), as well as in P3. It can also be said that there was deterioration in performance in the 2011 test in P2 and P4 in relation to 2010, except for the 3rd stage where C4 surpassed his 2010 performance in both situations, as can be seen in Table 14 and in Figures 59 and 60.

When comparing the $C_D$ values between the two years, however, a greater consistency in results was seen in 2010, reflected in there being an increase in $C_D$ for all position performed following an increase in wind velocity. This was not the case in T3 for P1, P2, P3 and P4 when a decrease in $\mathbf{C_D}$ was seen in nearly all situations, with the advancing of the stages. Incorporating calculation of the $\mathbf{C_D}$ according to the frontal area of the individual in the 2nd campaign in 2011 brought with it even more accurate values. The values for the **D Area** of C4 calculated from the frontal area at 30m/s represent $0.482m^2$ in P1, $0.493m^2$ in P2, $0.316m^2$ in P3 and $0.281m^2$ in P4.

**Postural Evaluation**

**Analysis of Lateral Photos**

In P1, both in 2010 and 2011, the volunteer was able to carry out and repeat the required posture with practically no alterations in the trunk position. It can be seen, however, that in 2010 he varied his arm position a little between the 3 distinct stages, whilst variations were more noticeable in 2011 in both the positioning of the arms and head. Comparing the postures adopted in one campaign to the next, fundamental differences can be seen in his head position (in 2011, C4 projects more to the front), in the position of the arms that are held further back in relation to the longitudinal axis of the body in 2011, and in the position of the outriggers, with the ends changing angle in the 3rd speed stage of T3.

In P2, it can be seen that C4 showed more consistency in his performance in 2011, whereas in 2010 the positioning of the arms presented more variation. When comparing postures between the two campaigns we can see that in 2011, C4 maintains a straighter trunk and elbows with more flexion. The angle of the outriggers also changes in the 3rd stage of the wind speed test.

In P3, it is observed that this was the position that C4 performed most consistently, both in 2010 and 2011, although in 2010 in the 3rd stage C4 had a more pronounced curvature of the trunk. When comparing the postures from the two campaigns together, it can be seen from the posture of C4 in 2010 that his back was more rounded than in 2011, when he also positioned his trunk further forward, bringing his shoulders into line with his knees.

In P4, the athlete adopted the posture of leading with both ski-poles held out to the front in 2010, whereas in 2011, this position had been altered so that the ski-poles were held in differing positions with one to the front and the other held lower. C4 could carry out and maintain the position with relative ease, particularly in 2011. When comparing the postures between the two campaigns, it was in P4 that the performance of C4 was most distinctly different between the two campaigns.

**Analysis of Frontal Photos**

An analysis of the postures held by C4 in the frontal plane for the two campaigns highlights that the volunteer is moving away from those postures held in 2010. In P1, the volunteer carried out the posture in 2011 with the arms held further away from the body. In P2, C4 completed the test in 2011 with his trunk held higher than in 2010 and with both arms further away from the body. In P3, although his performance of this position was more similar to 2010, his arms were still held further from the body. And in P4, the volunteer in fact maintained a different position in 2010 than the one he had performed in the WT, and also in 2011 he presented an unequal performance to that registered in

2010. It can be seen from the comparison of the diagrams created from the positions P1, P2, P3 and P4 held by C4 that there is a clear difference in the frontal area generated.

**Questionnaires**

Questionnaires applied in the 2nd campaign only, provided more important information regarding the perception of discomfort through use of the Body Discomfort Diagram. C4 noted feeling some discomfort in the in the lumbar and hip region and moderate discomfort in the legs, ankles and feet. C4 had not previously answered the first part of the questionnaire, making it difficult to gain an overall outline of his training year. It was possible, however, to apply the second and third parts of the questionnaire as these were answered *in loco*, and brought with them pre and post-test information.

His best result in the World Alpine Skiing Championships 2011 (Sestriere/ Italy), which took place between the two evaluation campaigns, was 9th place in the Down Hill race. He was disqualified in the Slalom and finished in 14th place in the Super G race. It is important to point out that the season ended without him having suffered any accident or significant injury.

In the replies related to the WT evaluation, it can be seen that C4 was able to safely and comfortably conduct the test, and thought it to be relatively easy. He believes the test results are important but does not know how they can be incorporated into his performance and training routine. His completion of the post-test questionnaire showed slight differences in relation to the answers given in the pre-test questionnaire, and he added to the information that he feels the most enjoyable test position performed to be P2.

From responses related to the investigation conducted at the Physiology Laboratory, it can be seen that C4 was able to perform the test safely and comfortably, principally from a cardiorespiratory and postural point of view. C4 thought the test to be hard, although his results show that he was not close to his $HR_{max}$. He considers these results to be more important than those found in the WT, which he believes do not add much to his training or performance routine. He also stated that his training had been modified to include numerous new ideas into his sessions as a result of the tests conducted in the Physiology Laboratory. Slight discrepancies were presented in the post-test questionnaire in relation to the replies given pre-test.

### 2.5 Case number 5/ Volunteer (C5)

The fifth case is an athlete from the male alpine ski team, born on 03/11/72, and having a disability classification of LW10/2 in the sitting skiers (monoskiers) category. He suffered a spinal cord injury in a work based accident that caused a fracture at the level of the eighth thoracic vertebra (T8), making him paraplegic. His condition is considered to be moderate/severe, resulting in his having little control over the muscles of the trunk and no control of the legs. He has practiced monoskiing since 1995 and trained for competitive competition with the *DPS* since 1998. He has obtained extraordinary results in the sport, having won 10 gold medals competing in Paralympic games. As can be seen from Table I (p.78), C5 is 173cm tall and weighed 75 kg at his last evaluation, through which it was possible to calculate his Body Mass Index as 25.06 kg/m$^2$.

#### 2.5.1 Tests

In the 2010 campaign, C5 was the sixth volunteer to conduct the ergometric treadmill test and the fourth in the wind tunnel. Session T1 involved spiroergometry evaluation carried out on the ergometric treadmill. Volunteer C5 had already taken part in such testing on seven previous occasions prior to 2010, and was able to follow the standard protocol and to prolong his performance as much as possible. The athlete was unfamiliar with the wind-tunnel test, never having taken part in such an evaluation before, but was able to complete all of the pre-planned steps.

**Cardiopulmonary Test**

**Preparations/ Control/ Immediately before/ During /After the test /Recovery**

Although athlete C5 had taken part in this type of testing in previous years, he was not the first athlete to carry out the treadmill evaluation on this occasion. The initial load encountered for T1 was 6.85N. The blood sample taken prior to the test showed a lactic acid concentration of 0.5mmol/L. The cardiac electrical activity of the volunteer was monitored closely during testing, together with the consistency of the recorded physiological values to ensure that none of the monitored recordings showed any warnings signs. The test session was brought to an end at the request of the athlete, having reached his limit of endurance. New blood samples were collected immediately at test end, and again 3min. and 5min. after the end, with these values being presented in Tables 16. After removal of the mouthpiece/mask, the participant was asked about the nature and intensity of the limiting symptoms, with his replies being recorded on a standard form. Routine post-tests were conducted during the recovery period to ensure that both ECG and systemic blood pressure measurements returned to normal before the release of the volunteer, and the official ending of the test session.

**Results of Cardiopulmonary Test 1**

The volunteer was required to pass a pre-test for the evaluative campaign before being allowed to take part in the actual testing session. The readings for HR and lactate levels, as well as the load values performed during spiroergometry are listed in Table 16 and in Figures 71, 72, and 73.

**Table 16 – Results of Test 1 for Athlete C5**

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 73 | 474 | 0.690 | 154.36 | 0.00 | 0.5 |
| 3 | 20 | 99 | 1228 | 0.676 | 398.28 | 5.02 | |
| 3 | 40 | 116 | 1545 | 0.782 | 515.09 | 7.77 | |
| 3 | 60 | 150 | 1902 | 0.918 | 656.56 | 9.14 | |
| 3 | 80 | 174 | 2283 | 0.961 | 796.28 | 10.05 | |
| 1min. 10s | 100 | 183 | 2501 | 1.015 | 884.07 | 11.31 | |
| | | | | | | | |
| After stop | | 184 | | | | | 11.1 |
| 1 | | 163 | | | | | |
| 2 | | 127 | | | | | |
| 3 | | 113 | | | | | 9.4 |
| 4 | | 112 | | | | | |
| 5 | | 109 | | | | | 9.3 |

$P_N$ – Mechanical output, HR - Heart Rate, $VO_2$ - Oxygen Consumption, RQ - Respiratory Quotient, $P_B$ Gross output, e - equivalent $P_N/P_B$, LA – Lactate.

**Figures 71, 72, and 73 – Results of Spiroergometry for athlete C5**

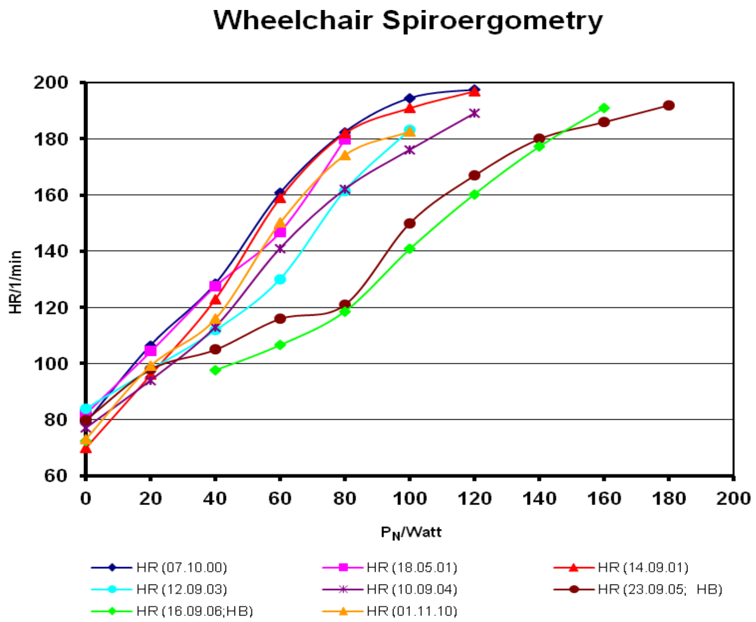



**Figure 71:** HR performance curve in relation to stage of testing, conducted since 2000 to 2010.

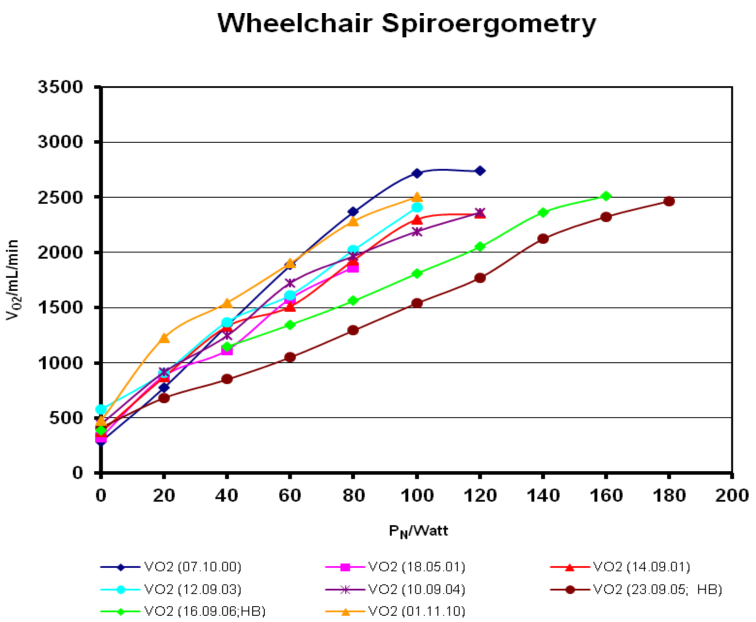



**Figure 72:** $\dot{V}O_2$ performance curve in relation to stage of testing, conducted since 2000 to 2010.

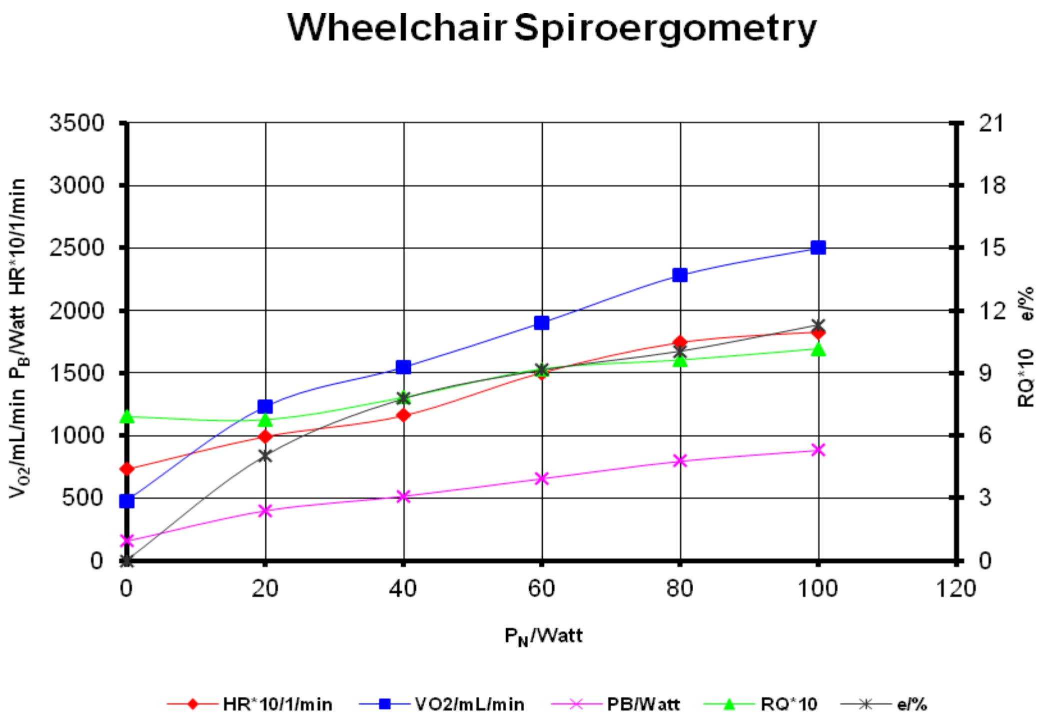



**Figure 73 –** Physiological data recorded during Test 1 in 2010.
Performance curves for HR, $\dot{V}O_2$, PB, RQ and "e", respectively

In this campaign, C5 was able to carry out the test with different loads in accordance with the protocol. From a biomechanical outlook, he presented long "strokes" and maintained a regular rate per minute. The tempo of his arm propulsion varied as the test stages advanced, although presenting a regular frequency per stage (1st stage 58 strokes/min., 2nd stage 64 strokes/min., 3rd stage 65 strokes/min. and 4th stage 68 strokes/min.). The highest load achieved by the athlete in the test was 100W (Mechanical Performance), reached during the 5th stage and maintained for 70s. From a physiological perspective, he was able to generate an output of 884.07W that represented an efficiency of 11.31%, presenting a $\dot{V}O_2$ of 2501mL/min (34.26mL.min$^{-1}$.kg$^{-1}$) and reaching the highest lactate level of 11.1mmol/L, followed by a lactate reading of 9.4mmol/L from the 2nd collection after 3 minutes and 9.3mmol/L from the 3rd collection after 5 minutes (Figure 74). His maximum HR achieved was 184bpm, measured immediately after test end, and his arterial blood pressure was 115/70mmHg, measured 5 minutes after test end.

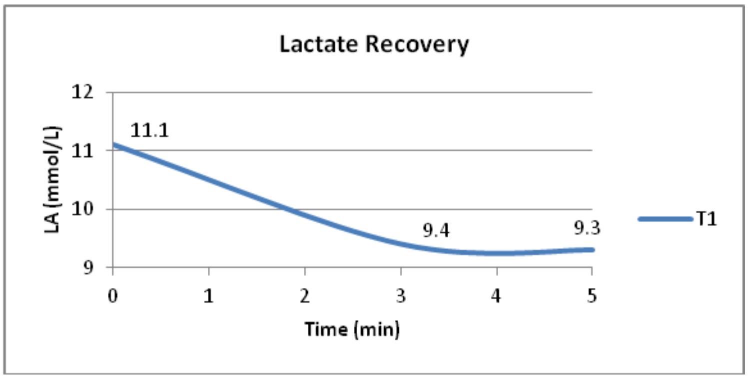



**Figure 74 –** Physiological data (lactate) after Test 1 conducted in 2010.

**Aerodynamic Test**

**Preparations/ Control/ Immediately before/ During /After the test /Recovery**

Athlete C5 was one of the athletes to spend the most time in the WT test section and to be exposed to more air flow. This was due to his performing an additional position (extra position with jacket) after completion of the standard pre-determined sequence.

The volunteer was monitored closely during testing in relation to both his personal safety and his execution of the required test positions. No contact occurred during testing between the support platform for the monoski and the WT floor. C5 consistently performed and repeated every position requested of him, showing no signs of fatigue during testing. The consistency of the force values together with the respective photographic records for the evaluated settings, were also ensured.

The endpoint for both tests was carried out by the technical team who were responsible for control management of the WT system and for the timing of photographic records for each position performed, as well as the interval between changes of velocity and position. The athlete was asked about the nature and intensity of the test after completion but voiced no complaints about the procedure or the steps performed. Spontaneous comments made by the athlete during T2 were recorded in field notes.

**Results of Aerodynamic Test 2**

C5 was able to complete the WT test in accordance with the outlined protocol, as can be seen in Table 17. In terms of coordination, he was also able to perform, maintain and repeat the requested positions with much precision.

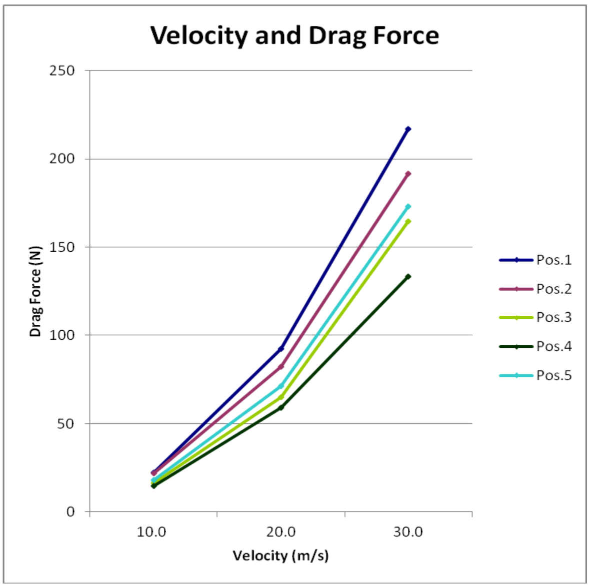
**Table 17 – Wind Tunnel Test Data for C5**

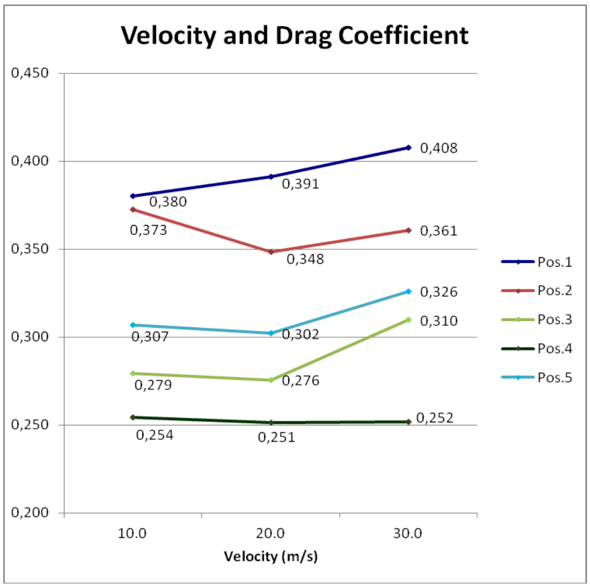
| Pos. | Velocity [m/s] | Drag Coeff. [-] | Drag Force [N] |
|---|---|---|---|
| Ref. | | **2010** | **2010** |
| 1 | 10.0 | (0.760) 0.380 | 22.44 |
| | 20.0 | (0.782) 0.391 | 92.54 |
| | 30.0 | **(0. 815) 0.407** | **216.99** |
| Ref. | | | |
| 2 | 10.0 | (0.745) 0.372 | 22.01 |
| | 20.0 | (0.696) 0.348 | 82.28 |
| | 30.0 | (0.721) 0.360 | 191.75 |
| Ref. | | | |
| 3 | 10.0 | (0.558) 0.279 | 16.50 |
| | 20.0 | (0.551) 0.275 | 65.15 |
| | 30.0 | (0.619) 0.309 | 164.38 |
| Ref. | | | |
| 4 | 10.0 | (0.509) 0.254 | **14.70** |
| | 20.0 | **(0.503) 0.251** | 58.93 |
| | 30.0 | **(0.504) 0.252** | 133.41 |
| Ref. | | | |
| 5 | 10.0 | (0,615) 0.307 | 18.16 |
| | 20.0 | (0,605) 0.302 | 71.26 |
| | 30.0 | (0,653) 0.326 | 173.03 |

Obs.: The values were obtained from the estimated frontal area of $0.5m^2$ of the athlete in 2010. The numbers highlighted in bold are the maximum and minimum values found in each session.

The largest drag force (**D**) presented by him was 216.99N in P1 at 30m/s, whilst the lowest **D** value for the test was 14.70N in P4 at 10m/s. The largest drag coefficient (**$C_D$**) presented by him for the test was 0.815 (0.407) in P1 at 30m/s, with the lowest **$C_D$** value being 0.503 (0.251) in P4 at 20m/s and also 30m/s.

It can be seen from the photographic records that follow that the values presented with respect to each photo have already been corrected, in order to construct the graphs.




**Figures 75 and 76 –** Performance curves for **D** and **CD** according to test stage performed in 2010.

**Description of Positions**

**Lateral photos recorded during the WT experiments**

*P1 – 10 m/s* – In this experiment (photo T2P1S1), the athlete presented with his trunk perpendicular to the ground. His arms are held a little back but along the body, with elbows bent (approx. 70º) and positioned next to the trunk. The ski poles are held diagonally in relation to the ground, whilst avoiding contact with it.

*P1 – 20 m/s* – In the photo (T2P1S2), the athlete reproduced the same position as at 10m/s, with the trunk positioned slightly further forward, elbows bent and the hands slightly raised.

*P1 – 30 m/s* – In the photo (T2P1S3), the athlete maintains his performance but with a subtle forward flexion of the neck, however, the position of the ski-tips are modified so that the frontal area of exposure is increased.

**Figure 77: Position 1 – Neutral Position**

10 m/s – photo T2P1S1 – Drag Coeff. 0.380

20 m/s – photo T2P1S2 – Drag Coeff. 0.391

30 m/s – photo T2P1S3 – Drag Coeff. 0.407

*P2 – 10 m/s* – For the second position (photo T2P2S1), the athlete assumed a forward flexion of the trunk (approx. 30º). Arms are held along the body and slightly to the front, with elbows bent (approx. 80º) and positioned close to the body at the height of the thighs. The hands are closer to the legs due to the forearms being further forward.

*P2 – 20 m/s* – In the photo (T2P2S2), the athlete reproduced a position almost equal to that assumed at 10 m/s, but with elbows bent slightly more.

*P2 – 30 m/s* – In the photo (T2P2S3), the athlete reproduced a position almost equal to that assumed at 20m/s, however, the angle of the ski-tips changed, increasing the frontal area of exposure.

**Figure 78: Position 2 – Run Position**

10 m/s – photo T2P2S1 – Drag Coeff. 0.372

20 m/s – photo T2P2S2 – Drag Coeff. 0.348

30 m/s – photo T2P2S3 – Drag Coeff. 0.360

*P3 – 10 m/s* – For the third position (photo T2P3S1), the athlete adopted a position of maximum forward flexion of the trunk (aprox. 40º). His arms are held perpendicular to the floor, with elbows bent (approx. 70º) and positioned next to the body at the height of the thighs. His forearms are further forward with his hands held slightly to the front, in relation to the line of the legs.

*P3 – 20 m/s* – In the photo (T2P3S2), the athlete reproduced the same position as at 10m/s, but bringing the chin a little closer to the knees and hands positioned slightly further back, with the skis rising as a consequence.

*P3 – 30 m/s* – In the photo (T2P3S3), the athlete reproduced a position almost equal to that assumed at 20m/s with just a small retreat of the hands and a subsequent alteration in the angle of the skis.

**Figure 79: Position 3 – "Aggressive" Position**

10 m/s – photo T2P3S1 – Drag Coeff. 0.279

20 m/s – photo T2P3S2 – Drag Coeff. 0.275

30 m/s – photo T2P3S3 – Drag Coeff. 0.309

*P4 – 10 m/s* – For the fourth position, (photo T2P4S1), the athlete maintains his trunk slightly more upright than for P3. He keeps his left arm placed as for P3, but his right arm is held in a new position with the elbow bent (approx. 90º), raising the ski-pole to a position above the line of the horizon (positive angle of attack). For the 2nd attempt (photo T2P4S1j) at the extra position whilst using a jacket, C5 is able to repeat the previously performed position with precision, with only a minor retraction of the right arm.

*P4 – 20 m/s* – In the photo (T2P4S2), the athlete reproduced a position almost equal to that assumed at 10m/s but with a greater forward flexion of the trunk. For the alternative attempt with jacket (photo T2P4S2j), the athlete assumed the same trunk position as at 10m/s but with his neck flexed slightly more and with a subtle retraction of the left arm.

*P4 – 30 m/s* – In the photo (T2P4S3), the athlete reproduced a position almost equal to that assumed at 20 m/s for the principal points of reference (head, arms, trunk, forearms and hands), but with the left ski-tip more angled. For the alternative attempt (photo E2P4S3j), C5 maintained his performance as at 20 m/s, however, with his trunk held slightly more upright and with a minor change in position of the right ski.

**Figure 80: Position 4 – Extra Position & Position 5 – Extra Position using a jacket**

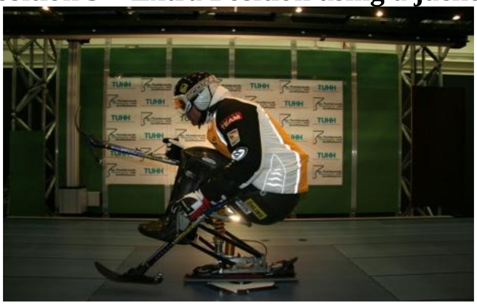



photo T2P4S1 – Drag Coeff. 0.254 **10 m/s** photo T2P4S1j – Drag Coeff. 0.307


photo T2P4S2 – Drag Coeff. 0.251 **20 m/s** photo T2P4S2j – Drag Coeff. 0.302


photo T2P4S3 – Drag Coeff. 0.252 **30 m/s** photo T2P4S3j – Drag Coeff. 0.326

The general results of the anthropometric evaluation and treatment of photographic records, as well as the field notes from the athlete for unique campaign, have now been presented. In addition to the results from the ergometric test and wind-tunnel performance, a follow-up by means of a discussion will now follow for the individual athlete under analysis.

### 2.5.2 Human Performance - Discussion

**Objectives Assessment**

The evaluation process was conducted with the intention of increasing the range of information and understanding of the performance structure that affects the world of the athletes from the *DPS*. It also aimed to analyse and compare individual results, contrasting them with other team members and to eventually relate these to other Paralympic athletes (e.g. wheelchair sports).

This athlete, born in November 1972, has a long history of training with the *DPS*. He participated in the 2010 Paralympic Winter Games in Vancouver, winning 3 gold medals (Super Combined, Giant Slalom, and Slalom) and one silver medal (Super G) in the sitting competitions. He was exemplary in his performance of the experiments developed over the two evaluative campaigns of this study and presented interesting and respectable results for this competitive sport, as well as for the scientific community.

**Anthropometric Assessment**

From the anthropometric measurements taken of C5, it was observed that the volunteer presented a body weight of 75kg with a height of 173cm, enabling calculation of his body mass index of 25.06kg/m$^2$, which remains within the range considered as normal according to The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults, (National Institutes of Health, 2000).

**Physiological Assessment**

Spiroergometry procedures were used to analyse the general fitness condition and cardiopulmonary system function of this athlete. He was able to respond well to the different load situations in testing completed in 2010, as well as previously in tests conducted in 2000. The author of this study was able to use these previous results presented by C5 as a comparison parameter to gauge the performance evolution of the athlete. In his most recent assessment as an athlete of the *DPS* (2010), he presented coherent and consistent results without being exposed to risk (Vinagre *et al*, 2012). These results are indirectly comparable to the results of evaluations made in each of the studies presented by the authors in Table 18, organised by Bhambhani (2002). It should be noted that the results encountered in Table 18 refer to trained and untrained individuals in wheelchair sports.

It can be said that C5 produced a very good performance in 2010 as he was able to continue the test for 13min 10s until the 5th stage, presenting a $HR_{max}$ of 184bpm and $\dot{V}O_2$ of 2501ml/min (33.34 ml/kg/min). The peak HR reached by the volunteer was equivalent to the $HR_{max}$ in relation to the pre-determined $HR_{max}$, as determined by the Karvonen formula (Robergs 2002, Policarpo 2004). The HR reading for the athlete, measured 3 minutes after the end of T1 was below 140bpm (113bpm), indicating very good cardiovascular conditioning due to the nature of his recovery. Table 18 verifies the results presented in these experiments, although the volunteer ages for the subjects included in those tests are not included. The HR values for the test conducted in 2010 were compared with those of 2000 (HR was slightly lower in 2010 than in 2000) and it can be stated that a very similar performance occurred in both tests. The athlete reached a HR of 184bpm for a load of 100W in 2010, while in 2000 his HR was 197bpm for a load of 120W, as shown in Figure 71.

In assessing the functional capacity of C5, we must look at the mechanical and physiological performance and the relationship between them (Wüpper, 2002). Athlete C5 was able to advance to the 5$^{th}$ stage (100W) of the experiment and continue there for 1min 10s. From a physiological perspective he was able to generate 884.07W, representing an efficiency of 11.31%. It can be seen by comparing the $\dot{V}O_2$ figure presented by the athlete in 2010 with that of the year 2000 test that there was deterioration in his more recent performance, even though in the early stages the athlete had presented a $\dot{V}O_2$ greater than in 2000. In the earlier test, where the athlete reached a $\dot{V}O_2$ of 2740 mL/min (36.53mL.min$^{-1}$.kg$^{-1}$), his efficiency was 12.23%, therefore, superior to the results from 2010, as can be seen in Figure 72.

**Table 18 – Peak Aerobic Power in Trained and Untrained Male Wheelchair Athletes with Paraplegia**

| Study | Mode | n | ISMGF classification | Lesion | $VO_2$ (L/min) | $VO_2$ (ml/kg/min) | HR (beats/min) |
|---|---|---|---|---|---|---|---|
| **Trained** | | | | | | | |
| Bernard et al. | WERG | 7 WA | II, III | T1- T10 | 2.35 | 34.3 | 169 |
| Campbell et al. | WCT | 10 WA | | T2-L2 | 1.91 | | 196 |
| Cooper et al. | WERG | 11 WR | II-IV | T3-L1 | 2.46 | 37.4 | 186.5 |
| Huonker et al. | WERG | 29 WA | II-V | T1-S2 | 2.42 | 34.5 | 183.3 |
| Okuma et al. | WCT | 8 WR | | T7-L1 | 2.44 | 46.5 | 169 |
| Price Campbell | ACE | 11 WA | | T3-4-L1 | 2.04 | 30.5 | 185 |
| Van der Woude et al. | WERG | 8 WA | | T3-L1 | 2.04 | 32.9 | |
| Vinet et al. | WCT | 8 WA | III-V | T8-L5 | 2.67 | 40.6 | 174 |
| **Untrained** | | | | | | | |
| Huonker et al. | WERG | 20 UT | II-V | T1-S2 | 1.76 | 23.9 | 161.8 |

ACE – arm crank ergometer; i – incomplete lesion; ISMGF International Stoke Mandeville Games Federation functional classification; n – sample size; $VO_2$ - Oxygen Uptake; UT – untrained participants; WA – wheelchair athletes (mixed group of athletes); WCT – wheelchair mounted on treadmill; WERG – wheelchair ergometer. Table incomplete, taken from an article by Yagesh Bhambhani (2002).

It can be seen from the lactate levels encountered in the tests conducted by C5 that practically no fluctuations in lactate levels occurred during the first five minutes of the post-test recovery period. The regenerative response of the volunteer was regressive with the athlete showing a lactate concentration peak after the test had ended, followed by consistently lower values in the follow-up measurements. The response of the volunteer in terms of age factor can be considered as better than his team colleagues as his performance and efficiency were among the best results found.

The evaluation conducted in this study intends to bring with it athlete results that can be used to establish parameters for the team as a whole, taking into account developmental history and performance results over a period of time of a skier. The athlete C5 has presented results that can be considered as a reference for this sport (Silva & Torres, 2002).

**Aerodynamic Evaluation**

The aerodynamics evaluation was intended to take account of the amount of drag produced by the athletes and it generated innovative results without exposing C5 to risk. C5 conducted his test within the parameters that were asked of him and gave a high level of performance. He presented very competitive readings in virtually all the positions completed by him in comparison to his colleagues, even though he has a larger body mass. As can be seen in Table 17 and Figures 75 and 76, the values obtained from the athlete in testing are quite consistent.

When analysing the performance of C5 in 2010, it can be said from looking at the **D** values that he was able to reproduce the highest **D** value (216.99N) of all the sit-ski athletes evaluated in the posture that offers the most resistance, P1 at 30m/s. When comparing P4 with P5 (an additional position and variation of P4 but wearing a jacket pulled over the top of the monoski) a deterioration in performance is evident. For the remaining positions performed, the athlete always obtained higher **D** values, proportional to the new wind speed, as can be seen in Table 17 and Figures 75 and 76.

In terms of analysis of $\mathbf{C_D}$ figures found during testing, it can be seen that the response in P1 was progressive, that is, the $\mathbf{C_D}$ values increased as the wind speed increased. In positions P2 and P3, however, this pattern was not observed with their being a lower $\mathbf{C_D}$ figure produced at 20m/s as compared to 10m/s and a higher figure once more at 30m/s. The response in P4 was virtually the same regardless of the wind speed applied to the athlete.

**Postural Evaluation**

**Analysis of Lateral Photos**

It should be noted that during his performance of T2, the athlete C5 performed an additional position after the standard sequence. This fifth position was the same as P4 but with the addition of a jacket worn by him and pulled over the top edge of the monoski. In P1, the volunteer was able to carry out and repeat the posture with only a small alteration in head position. In P2, the athlete showed consistency in his performance with a small alteration in arm position in the third stage. The position P3 proved to be the one that C5 performed with less homogeneity, showing changes in the positioning of the arms and ski-poles, with these becoming lower as the stages progressed. For the first 3 positions carried out, it can be seen that the ends of the outriggers altered their angle under the pressure of the wind at 30m/s, becoming more flexed.

A comparison could be made in P4 with the additional performance given in P5. It can be seen that despite the alternate placing of the ski-poles from the previous positions, C5 was able to perform the 3 different stages of this position with only a very slight increase in forward flexion of the trunk as the wind speed increased. Very little difference is seen between P4 and P5 when comparing the two together, with almost identical physical performances, however, the measured values encountered differ significantly and favour the version adopted in P4.

### 2.6 Case number 6/ Volunteer (C6)

The sixth case is an athlete from the female alpine ski team, born on 02/10/89. She has a disability classification of LW 6/8-2, being a skier with a congenital abnormality (dysmelia) resulting in the lack of a left hand and thus, she only uses one ski-pole. She has participated in Alpine Skiing since 1999, taking part in competitions organized by the German Ski Federation. From 2000, she began her participation in international competition for the German National Paralympics Committee (*DPS*), taking part in the Winter Paralympic Games of 2006 and 2010. In Vancouver, she won a total of 4 medals in competition, this being 2 silvers and 2 bronze.

As can be seen from Tables I and II (p.78), C6 is 163cm tall and weighed 59.5kg at her last evaluation, giving her a Body Mass Index of 21.83kg/$m^2$. Measurements of the volunteer's seated height and arm-span were also taken during the latter evaluative campaign, which allowed her Cormic Index and relative arm-span to be determined.

#### 2.6.1 Tests

In the first campaign, C6 was the fifth participant to take part in ergometric testing, which she conducted using an ergometric bicycle, whilst she was the third person to be evaluated in the wind-tunnel. For the second campaign, C6 was the last athlete to be evaluated in both the ergometric and aerodynamics tests. Tests 1 and 4 involved ergometric testing and athlete C6 prolonged her performance during them for as long as she could. Test 1 in the initial campaign did not involve the analyses of gases, but this was included in test 4 of the second campaign, with the volunteer being equipped with a gas analyser during evaluation. C6 had never before taken part in aerodynamics testing in a wind tunnel, such as occurred in tests 2 and 3, and she is the first Paralympic standing-skier from the German team to take part in such an evaluation.

**Cardiopulmonary Test**

**Preparations; Control; Immediately before, During, After the test; Recovery**

The initial load for both tests was 30W, increasing with each new stage by 40W. Blood samples were collected before each test, during the stages, immediately at test end, and again 3min. and 5min. after the end, with these values being presented in Tables 19 and 20. The cardiac electrical activity of the volunteer was monitored closely during testing, together with the consistency of the recorded physiological values to ensure that none of the monitored recordings showed any warnings signs. Both test sessions were brought to an end at the request of the athlete, having reached her limit of endurance. The volunteer was asked at this time about the nature and intensity of the limiting symptoms, with the replies being recorded on a standard form. During the recovery period for T4, routine post-tests were conducted to ensure that both ECG and systemic blood pressure measurements returned to normal before releasing the athlete.

### Results of Cardiopulmonary Tests 1 and 4

The volunteer was required to pass a pre-test for both evaluative campaigns before being allowed to take part in the actual testing session itself. The results of T1, conducted without gas analysis, can be seen in Table 19.

**Table 19 – Results of Test 1 for Athlete C6**

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | $P_B$ (Watt) | LA (mmol/L) | RPM |
|---|---|---|---|---|---|---|
| 0 | 0 | 88 | | | 0.7 | |
| 3 | 30 | 107 | | | 0.8 | 83 |
| 3 | 70 | 125 | | | 1.0 | 85 |
| 3 | 110 | 153 | | | 2.5 | 85 |
| 3 | 150 | 174 | | | 5.6 | 78 |
| 3 | 190 | 193 | | | 11.8 | 75 |
| | | | | | | |
| 3 | | 133 | | | 10.8 | |
| 5 | | 122 | | | 12.0 | |

$P_N$ – Mechanical output, HR - Heart Rate, $VO_2$ - Oxygen Consumption, $P_B$ Gross output, LA – Lactate, RPM – Revolutions per minute.

**Figure 81 – Results of test 1 for athlete C6**

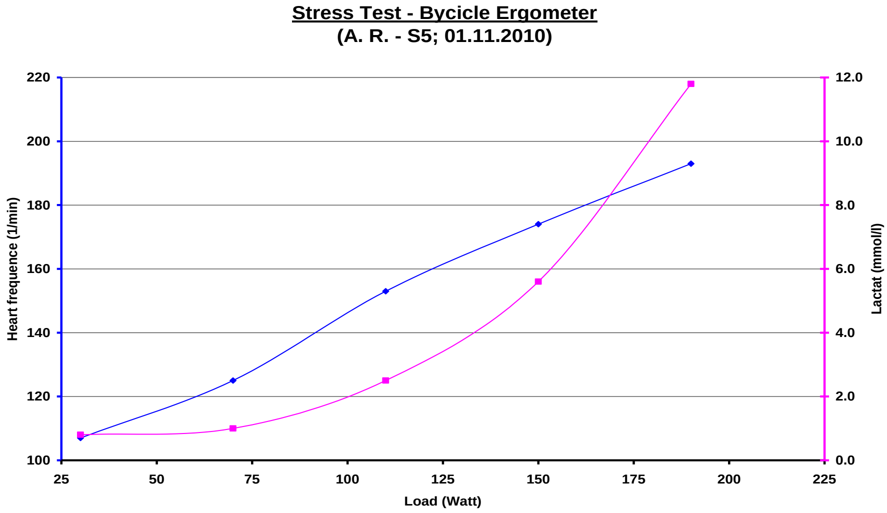



**Figure 81:** Performance curves for HR and Lactate levels in relation to stage of testing for evaluation conducted in 2010.

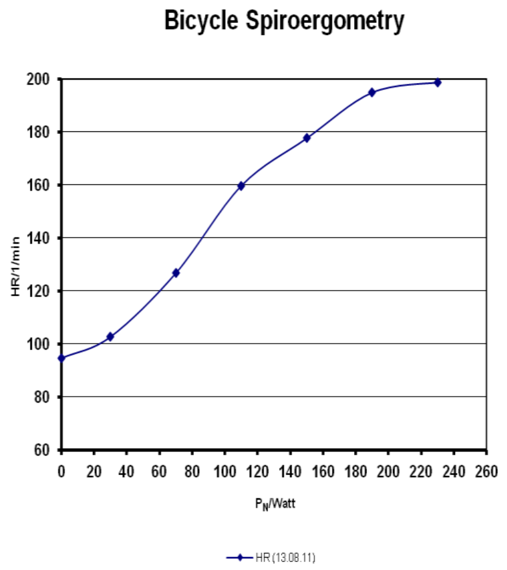
The results of T4 conducted with analysis of $\dot{V}O_2$ can be seen in Table 20. The maximum HR and the load values obtained during the spiroergometry are detailed in Figures 82, 83 and 84.

**Table 20 – Results of Test 4 for Athlete C6**

| Time (min) | $P_N$ (Watt) | HR (bpm) | $VO_2$ (mL/min) | RQ | $P_B$ (Watt) | e (%) | LA (mmol/L) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 95 | 338 | 1.085 | 121.50 | 0.00 | 0.8 |
| 3 | 30 | 103 | 777 | 0.893 | 266.37 | 11.26 | 1.0 |
| 3 | 70 | 127 | 1157 | 0.976 | 405.21 | 17.27 | 1.5 |
| 3 | 110 | 160 | 1521 | 1.036 | 540.35 | 20.36 | 2.5 |
| 3 | 150 | 178 | 1953 | 1.112 | 706.82 | 21.22 | 5.2 |
| 3 | 190 | 195 | 2238 | 1.293 | 844.54 | 22.50 | 8.3 |
| 1 min. 30s | 230 | 199 | 2366 | 1.245 | 882.96 | 26.05 | 14.2 |
| | | | | | | | |
| after test | | 199 | | | | | |
| 1 | | 177 | | | | | |
| 2 | | 158 | | | | | |
| 3 | | 141 | | | | | 12.3 |
| 4 | | 131 | | | | | |
| 5 | | 129 | | | | | 12.1 |

$P_N$ – Mechanical output, HR - Heart Rate, $VO_2$ - Oxygen Consumption, RQ - Respiratory Quotient, $P_B$ Gross output, e - equivalent $P_N$/ $P_B$, LA – Lactate.

**Figures 82, 83 and 84 – Result of test 4 for athlete C6**



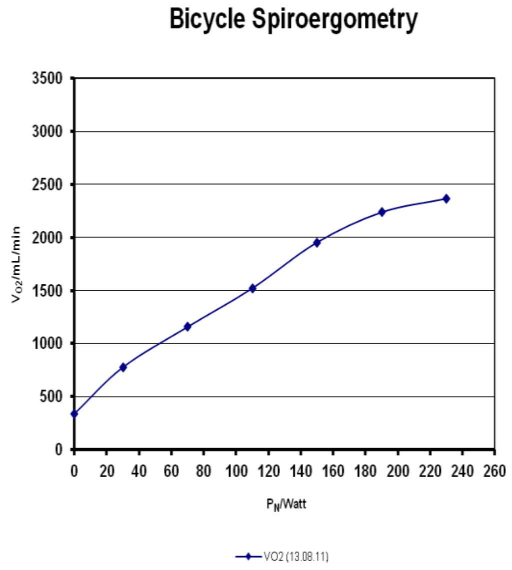




**Figure 82:** HR performance curve in relation to stage of testing, conducted in 2011
**Figure 83:** $\dot{V}O_2$ performance curve in relation to stage of testing, conducted in 2011.

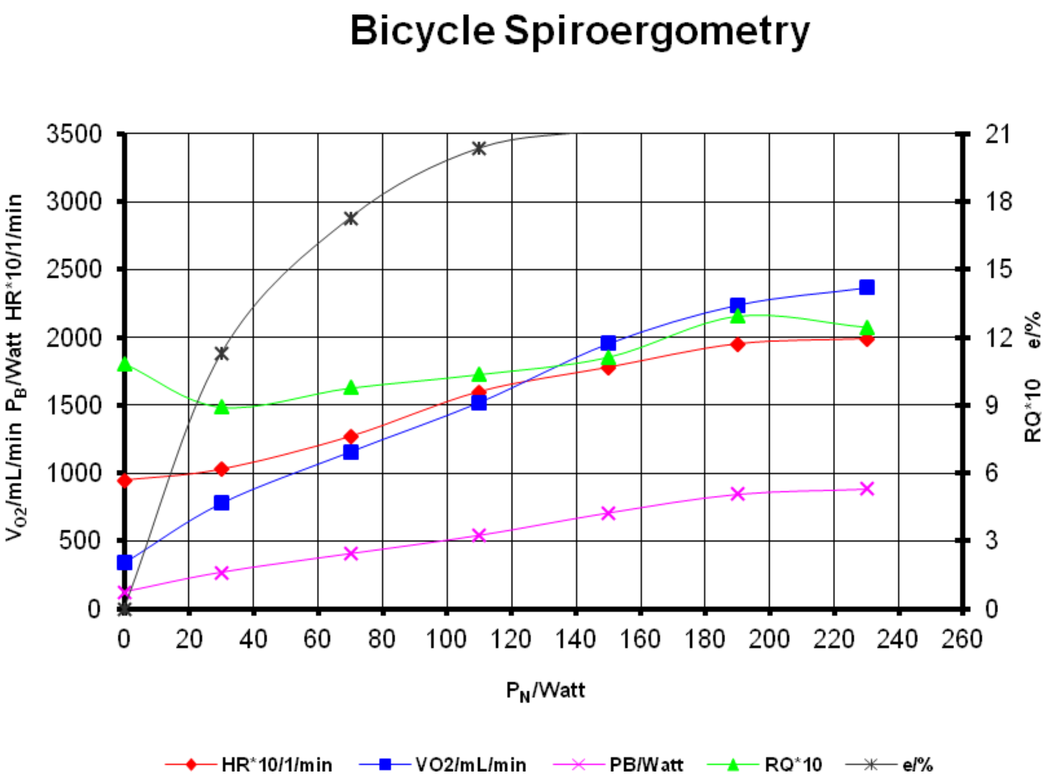



**Figure 84 –** Physiological data recorded during Test 4 in 2011
Performance curves for HR, $\dot{V}O_2$, $P_B$, RQ and of "e", respectively.

The athlete was able to carry out the test in the first campaign, with the load progressively increasing in accordance with the protocol. From a motor point of view, C6 was able to maintain a near constant rotation of the pedals as the stages advanced. A reduction in frequency, however, was observed for the last two stages of the test, as compared to the first 3 stages. The highest mechanical load ($P_N$) achieved by the athlete in T1 was 190W, whilst carrying out the 5th stage. The $P_B$ could not be calculated as the equipment used does not permit the reading of this data during testing. C6 presented a lactate reading of 11.8mmol/L immediately after the test end, followed by a reading of 10.8mmol/L from the 2nd collection after 3 minutes and 12mmol/L from the 3nd collection after 5 minutes (Figure 85). As can be seen in Table 19, the maximum HR reached in T1 was 193bpm measured immediately after the test end.

In the 2nd campaign, C6 conducted the test again in accordance with the protocol, and showed good motor fluency throughout the entire evaluation. The athlete did not reach the 7th stage but was able to continue for 1min 30s into the 6th stage, maintaining good posture and achieving the highest mechanical load for T4 of 230W. Additional equipment was available for use with this evaluation, and although a direct comparison cannot be made between this and the previous test, it does demonstrate an evolution in the evaluative process. The $P_B$ was calculated to be 882.96W and a comparison established between the two quantities of 26.05%, which is the highest relationship found between the athletes as an absolute and not relative value. It is important to note that for this campaign C6 was using footwear with straps as opposed to T1 where she used pedals with straps. She presented a $\dot{V}O_2$ of 2366mL/min and a lactate level of 14.2mmol/L immediately after the test end, followed by a lactate reading of 12.3mmol/L from the 2nd collection after 3 minutes and 12.1mmol/L from the 3nd collection after 5 minutes (Figure 85). The maximum HR reached in T4 was 199bpm, measured immediately after the test end and presented in Table 20.

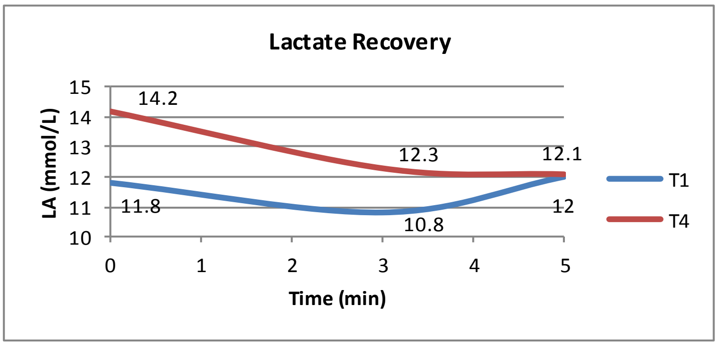



**Figure 85 –** Physiological data (lactate) after Test 1 and Test 4 conducted in 2010 and 2011 respectively.

**Aerodynamic Test**

**Preparations; Control; Immediately before, During, After the test; Recovery**

The volunteer was monitored closely during testing in relation to both her personal safety and performance of the test positions to be carried out. No contact occurred during testing between the support platform for the skis and the WT floor. The athlete presented some difficulties in distinguishing and executing the 3 different positions for both the first and second campaigns, and at times it was not clear from her performance, which of the 3 distinct positions she was carrying out. Additionally, C6 was not able to complete all of the required stages for the WT test in the first campaign, however, by the second campaign she managed to perform all stages at the 3 different wind speeds.

Consistency of the force values along with the respective photographic records for the evaluated settings, were ensured. The endpoint for both tests was carried out by the technical team who were responsible for control management of the WT system and for the timing of photographic records for each position performed, as well as the interval between changes of velocity and position.

The athlete was asked about her experience of the nature and intensity of this evaluation method after completion of the test, and voiced no complaints. Spontaneous comments made by the athlete during T2 were recorded in field notes, and a questionnaire was applied both before and after the evaluation for T3.

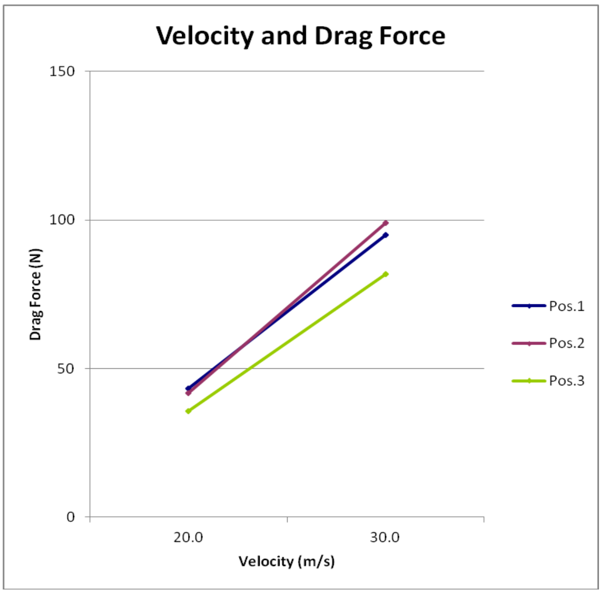
**Results of Aerodynamics Tests 2 and 3**

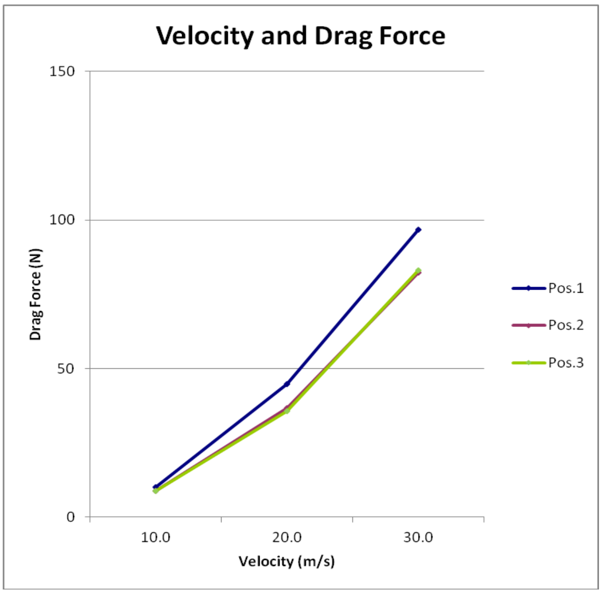
C6 was not able to complete all of the WT stages defined in the protocol, as can be seen from the photgraphic records and in Table 21. In terms of coordination, she could perform, maintain and repeat the requested positions with ease. The largest drag force (**D**) presented by her was 99.01N for T2 in P2 at 30m/s, whilst for T3 she recorded a value of 96.68N in P1 at 30 m/s. Her lowest **D** value for T2 was 35.74 N in P3 at 20 m/s, whereas for T3 the lowest value found was 8.72N in P2 at 10 m/s. The largest drag coefficient (**$C_D$**) presented by her was 0.195 for T3 in P2 at 20 m/s, and for T2 this value was 0.372 (0.186) in P2 at 20 m/s. Her lowest **$C_D$** value for T2 was 0.303 (0.151) in P3 at 20 m/s, whilst for T3 she presented a value of 0.155 in P4 at 20 m/s.

**Table 21 – Wind Tunnel Test Data for C6**

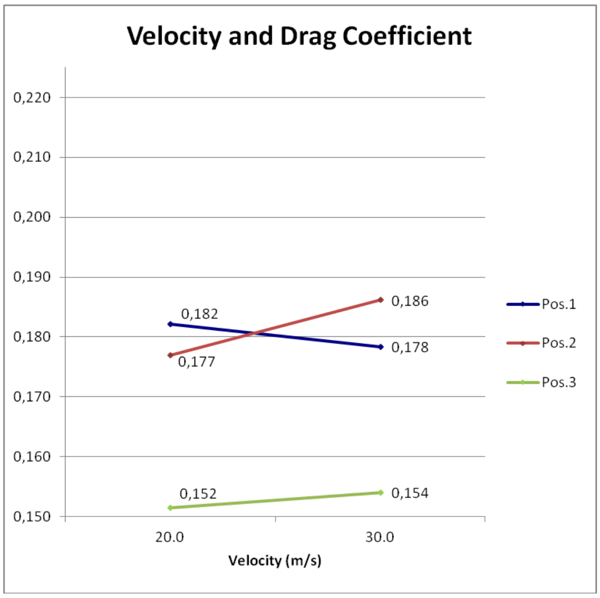
| Pos. | Velocity [m/s] | $C_D$ [-] 2010 | $C_D$ [-] 2011 | Area [m$^2$] 2011 | $C_D$ v2 [-] 2011 | D Area [m$^2$] 2011 | Drag Force [N] 2010 | Drag Force [N] 2011 |
|---|---|---|---|---|---|---|---|---|
| Ref. | | | | | | | | |
| 1 | 10.0 | | 0.180 | 0.7181 | 0.2512 | 0. 129 | | 10.16 |
| | 20.0 | (0.364) 0.182 | **0.195** | 0.7181 | 0.2712 | 0.140 | 43.19 | 44.87 |
| | 30.0 | (0.357) 0.178 | 0.184 | 0.7181 | 0.2566 | 0. 132 | 94.98 | **96.68** |
| Ref. | | | | | | | | |
| 2 | 10.0 | | **0.155** | 0.6642 | 0.2331 | 0.102 | | **8.72** |
| | 20.0 | **(0.372) 0.186** | 0.159 | 0.6642 | 0.2394 | 0.105 | 41.77 | 36.59 |
| | 30.0 | (0.354) 0.177 | 0.157 | 0.6642 | 0.2364 | 0.104 | **99.01** | 82.26 |
| Ref. | | | | | | | | |
| 3 | 10.0 | | 0.156 | 0.6453 | 0.2416 | 0.100 | | 8.78 |
| | 20.0 | **(0.303) 0.151** | **0.155** | 0.6453 | 0.2402 | 0.100 | **35.74** | 35.69 |
| | 30.0 | (0.308) 0.154 | 0.158 | 0.6453 | 0.2456 | 0.101 | 81.74 | 83.04 |

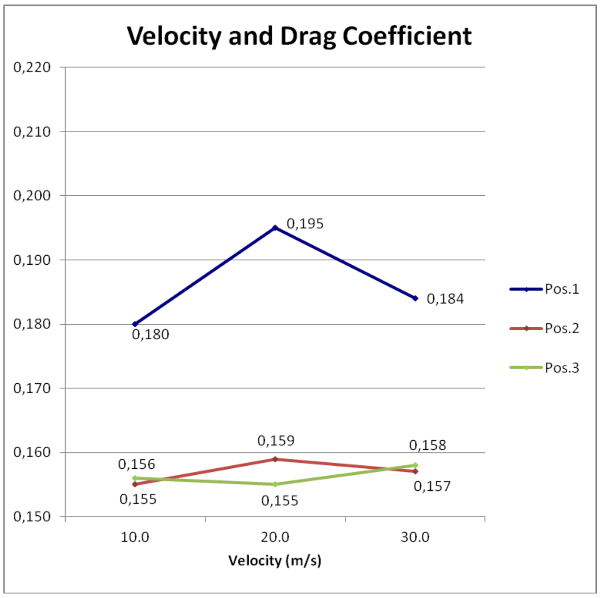
Obs.: The values were obtained from the estimated frontal area of 0.5m$^2$ of the athlete in 2010 and 1m$^2$ in the 2011 test. The numbers highlighted in bold are the maximum and minimum values found in each session. The colours green and orange represent an improvement or deterioration in performance, respectively. The blue represents the values found for the CD from experiment 3 for the new values calculated of the frontal area based on the technique of counting pixels of digital photographs.




**Figures 86 and 87 –** Performance curves for **D** according to test stages performed in 2010 and 2011.




**Figures 88 and 89 –** Performance curves for **CD** according to test stages performed in 2010 and 2011.

It can be seen from the photographic records that follow that the values presented with respect to each photo have already been corrected, enabling a direct comparison to be made. Similarly, these values were also used in the construction of comparative graphs between each campaign and configuration performed.

**Description of Positions**

**Lateral Photos Recorded during the WT Experiments**

*P1 – 10 m/s* – In the photo (T3P1S1) made during T3 it can be seen that the athlete adopts a standing position, with knees bent at an angle greater than 90º, and with the body bent over at the hips, which are held in a position above the level of the shoulders. The trunk is supported over the thighs with the arms resting on the knees. The elbows are located at the height of the knees and bent at an angle of more than 90º. The hand securing the ski-pole is located to the front of the face and the neck is extended, with the eyes focused to the front and ground.

*P1 – 20 m/s* – In the 1st exp. (photo T2P1S2), the athlete adopted a standing position with knees flexed (approx. 90º) and hips bent and elevated to a position higher than the shoulders. The trunk is supported over the thighs with the arms resting on the knees. The elbows are located lower than the knees and bent at an angle of more than 90º. The hand securing the ski-pole is to the front of the face and the neck extended with the eyes focused to the ground. In the 2nd exp. (photo T3P1S2), it can be seen that C6 reproduced a posture very similar to that of the previous year, however, her body is shifted more to the front.

*P1 – 30 m/s* – In the 1st exp. (photo T2P1S3), the athlete's body is held a little further back, with a slight lowering of the hips in relation to the previous performance. In the 2nd exp. (photo T3P1S3), the athlete reproduced the same position as at 20 m/s, but again with the body held a little further back to a more central position, as also seen in T2.

**Figure 90: Position 1 – Tucked Position**

**10 m/s** photo T3P1S1 – Drag Coeff. 0.180

photo T2P1S2 – Drag Coeff. 0.182 **20 m/s** photo T3P1S2 – Drag Coeff. 0.195

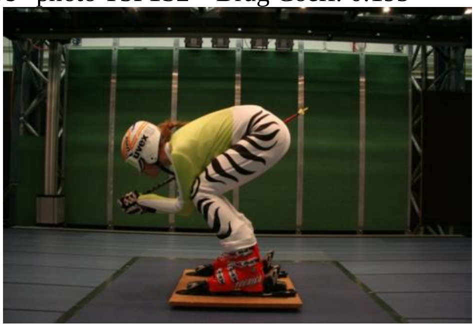


photo T2P1S3 – Drag Coeff. 0.178 **30 m/s** photo T3P1S3 – Drag Coeff. 0.184

*P2 – 10 m/s* – In the photo (T3P2S1), the athlete can be seen in a crouched position with knees bent at an angle greater than 90º, and hips bent and held at the same level as the shoulders. The trunk is supported over the thighs with the arms resting on the knees. The elbows are positioned lower than the knees and bent at an angle greater than 90º. The hand holding the ski-pole is further forward than the head, and the athlete's neck is extended with her eyes directed to the ground.

*P2 – 20 m/s* – In the 1st exp. (photo T2P2S2), the athlete is stood and in a similar position to P1, with knees flexed (approx. 90º) and hips bent and held above the line of the shoulders. The trunk is again supported over the thighs with the arms resting on the knees. The body is positioned further forward than for the previous position. In the 2nd exp. (photo T3P2S2), the knees are seen to be bent to a greater degree, with the hips more at shoulder height and the forearm held closer to the face.

*P2 – 30 m/s* – In the 1st exp. (photo T2P2S3), the posture is maintained as per the previous speed but with a slight elevation of the arms. In the 2nd exp. (photo T3P2S3), the athlete keeps the posture as at 20 m/s, however, the body is held slightly further back in a more central position.

**Figure 91: Position 2 – Run Position**

**10 m/s** photo T3P2S1 – Drag Coeff. 0.155

photo T2P2S2 – Drag Coeff. 0.177 **20 m/s** photo T3P2S2 – Drag Coeff. 0.159

photo T2P2S3 – Drag Coeff. 0.186 **30 m/s** photo T3P2S3 – Drag Coeff. 0.157

*P3 – 10 m/s* – In the photo (T3P3S1), the athlete is in the crouched position with knees bent at an angle greater than 90º, and hips held lower than the line of the shoulders. The trunk is positioned over the thighs and the arms resting on the knees. The bent elbows (approx. 90º) are at knee height, the hand securing the ski-pole is positioned to the front of the head, and the neck extended with eyes directed to the front.

*P3 – 20 m/s* – In the 1st exp. (photo T2P3S2), the athlete is in the crouched position with knees bent at an angle greater than 90º, and hips held in line with the shoulders. The trunk is held over the thighs, with arms resting on the knees and elbows slightly below the knees. The body is in a more central position. In the 2nd exp. (photo T3P3S2), the knees can be seen to be bent more, hips held still lower than the shoulders, and the fore-arm closer to the face.

*P3 – 30 m/s* – In the 1st exp. (photo T2P3S3), the posture is maintained, with a slight extension of the elbows bringing the hand still further forward. In the 2nd exp. (photo T3P3S3), the athlete maintains her performance as at 20 m/s, however, with less flexion of the knees allowing a slight elevation of the hips.

**Figure 92: Position 3 – "Egg form"**

**10 m/s** photo T3P3S1 – Drag Coeff. 0.156

photo T2P3S2 – Drag Coeff. 0.151 **20 m/s** photo T3P3S2 – Drag Coeff. 0.155

photo T2P3S3 – Drag Coeff. 0.158 **30 m/s** photo T3P3S3 – Drag Coeff. 0.158

**Frontal Photos Recorded after the WT Experiments**

*P1 – No wind* – In the photo (T3P1) it can be seen that the athlete is positioned with the neck extended and her eyes directed to the front and to the ground. Her arms are placed perpendicular to the trunk, with elbows positioned to the front and supported by the knees. Her hand is positioned to the front and holding the *ski pole*. The knees are bent and positioned closer together than the feet underneath. The legs are located side by side with an average spacing between them and the feet pointed to the front and fixed to the ski support base. This photo was the origin of the diagram (T3P1v2) from which the calculation of the frontal area of the standing-skier was made in P1.

**Figure 93: Position 1 – Tucked Position**


photo T3P1 T3P1v2

*P2 – No wind* – In the photo (T3P2) the athlete can be seen with her neck extended and her eyes directed to the front and to the ground. Her arms are placed perpendicular to the trunk, with the elbows positioned to the front of the knees. The knees are situated between the inner surfaces of the arms. The hand placed to the front is at the height of the knees and secures the *ski pole*. The knees are bent further than in P1 and are positioned apart at almost the same width as the feet. The legs are located side by side with an average spacing between them and the feet pointed to the front and fixed to the ski support base. This photo was the origin of the diagram (T3P2v2) from which the calculation of the frontal area of the standing-skier was made in P2.

**Figure 94: Position 2 – Run Position**

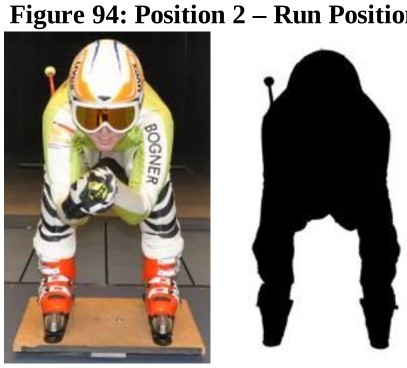



photo T3P2 T3P2v2

*P3 – No wind* – In the photo (T3P3) the athlete is positioned with an extended neck and with her line of vision directed more to the front than to the ground. Her arms are situated to the front of the trunk, with the knees being flanked by the inner surfaces of the arms, and the elbows positioned to the front of the knees. The hand is held to the front, securing the *ski pole* at the height of the mouth. The knees are bent further than in P2 and are positioned apart at almost the same width as the feet. The legs are located side by side with an average spacing between them and the feet pointed to the front and fixed to the ski support base. This photo is the origin of the diagram (T3P3v2) used to calculate the frontal area of the standing-skier in P3.

**Figure 95: Position 3 – "Egg form" Position**


photo T3P3 T3P3v2

The general results of the anthropometric evaluation, the treatment of the photographic records, and the questionnaires and field notes completed by the athlete for both campaigns have now been presented. We would now like to put forward, in addition to the individual results presented in relation to tests performed on the ergometric bicycle, and in the wind tunnel, a follow-up of the individual analysis by means of a discussion for the athlete in question.

### 2.6.2 Human Performance - Discussion

**Objectives Assessment**

The evaluative process was conducted with the intention of increasing the range of information and understanding about the performance structure that affects the world of this athlete from the *DPS*. It also aimed to analyse her results and to compare between her own performances, with those of her fellow team members, and also with the results of non-disabled athletes from the sport of Alpine Skiing.

This athlete, born in October 1989, has a long history of training with the *DPS* and participated in the 2010 Paralympic Winter Games, achieving second place in the Slalom and Giant Slalom races and third place in the Down Hill and Super-G races in the standing class competitions. The athlete presented exemplary conduct during the development of these experimental studies. She had some difficulties in clearly distinguishing the different positions that should be carried out during testing, which became clearer in the 2$^{nd}$ campaign with a difficulty in replicating the postures adopted in the 1$^{st}$ campaign. Nonetheless, the results that were obtained were interesting and respectable for this competitive sport, as well as for the scientific community.

**Anthropometric Assessment**

From the anthropometric measurements taken, it was observed that the volunteer reduced her body weight from 59.5kg to 58kg during the period between the two evaluative campaigns. As a consequence, this altered her body mass index with it reducing to 21.83kg/m$^2$, however, remaining within the range considered as normal according to "The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults" (National Institutes of Health, 2000).

The arm-span of athlete C6 (145cm) was measured in the 2nd campaign, making it possible to determine her relative arm-span (88.95). This figure is small although it should be remembered that C6 lacks a left hand, something that presents an extra difficulty from a motor point of view in terms of alpine skiing, as she must work hard with her legs and only one ski-pole to maintain her equilibrium and make directional changes. C6 was the only female representative in the standing class for alpine skiing from the athletes of the *DPS* in the 2nd campaign.

**Physiological Assessment**

A spiroergometry evaluation was carried out in 2010 to check the fitness condition of this athlete and brought with it sound results, although with some inconsistencies, without exposing her to risk. A further spiroergometry evaluation with the addition of equipment to collect and analyse the expired gases was conducted in 2011 with the same intention, and once again brought coherent and on this occasion, more consistent results, without exposing C6 to risk. The athlete produced similar performances following the same protocol in 2010 and 2011, although continuing the test to the next stage with a longer duration of 1’30s in 2011, and showing little difference in $HR_{max}$. From the results provided, it can be said that C6 in continuing to improve her aerobic performance.

In assessing the functional capacity of C3, we must look at the efficiency of the mechanical and physiological performance and the relationship between them (Wüpper, 2002). Athlete C6 was able to advance to and complete the 5th stage (190W) in T1, whilst for T4 she was able to advance to the 6th stage (230W) and continue there for 1min 30s. From a physiological perspective she was able to generate 882.69W, representing an efficiency of 26.05% with this figure showing a significant difference from results obtained by wheelchair users on a treadmill. The $\dot{V}O_2$ values presented by C6 in the 2nd campaign (2366mL/min – 40.79mL/kg/min) are considered quite high when compared to other sports such as athletics involving the visually impaired, as can be seen in Table 22.

**Table 22 - Treadmill Functional Capacity Values for Brazilian Visually Impaired Para-athletes (Female)**

| Name | $VO_2$ (L/min) | $VO_2$ (mL/kg/min) |
|---|---|---|
| A.S. | 2. 22 | 42.4 |
| M.F. | 2. 70 | 48.7 |
| Average | 2.46 | 45.6 |
| S.D. | 0.34 | 4.5 |

Partial table taken from an article by Silva (2002).

When comparing the $HR_{max}$ reached by C6 with her pre-determined $HR_{max}$ according to the Karvonen formula (Robergs 2002, Policarpo 2004), the volunteer reached submaximal HR in T1 and $HR_{max}$ in T2. Follow-up measurements taken 3 minutes after test-end showed her HR to be less than and approximately equal to 140bpm (133bpm and 141bpm, respectively), indicating good cardiovascular fitness, although there still lies room for improvement.

In relation to the lactate concentration values found during testing with C6, it can be seen that some fluctuation in lactate concentrations occurred in the 5 minutes after test-end during the recovery period for the 1st campaign, whereas no fluctuation occurred in lactate concentrations in this same period for the 2nd campaign. The recovery response of the athlete was gradual, with a peak concentration measurement being recorded at test-end, followed by consistently lower values for the subsequent recordings. Despite presenting these two different post-test responses over the two campaigns, it can be said that the recovery of the volunteer was satisfactory.

**Aerodynamic Evaluation**

The aerodynamics evaluation was intended to take account of the amount of drag produced by the athlete and generated innovative results without exposing C6 to risk. The distinct performances of C6 over the two campaigns showed only a partial improvement as she continued to present difficulties in defining a standard posture for her routine. Her results for the 2011 evaluation presented a certain inconsistency in the test values obtained, as can be seen in Table 21 and in Figures 86, 87, 88 and 89.

Comparing the results for **D** in 2011 with those of 2010, it can be seen that C6 was only able to reduce the drag produced in P2. The athlete presented better performances in 2010 as opposed to 2011for the remaining positions (P1 and P3), as can be seen in Table 21 and Figures 86 and 87.

Likewise, when comparing the $\mathbf{C_D}$ values encountered in 2011 with those of 2010, an inconsistency can be seen in the results with the expected outcome as the wind speed increased being found only in the transition from the 2$^{nd}$ to the 3$^{rd}$ stage in T2. This was not the case in T3 for P1 and P2 when a decrease in the $\mathbf{C_D}$ figures presented by C6 occurred when passing from the 2$^{nd}$ (20m/s) stage to the 3rd (30m/s) stage. Even more accurate values were produced in the 2$^{nd}$ campaign in 2011 by incorporating calculation of the $\mathbf{C_D}$ according to the frontal area of the individual, than those encountered in 2010 or in experiments conducted in the 1970's (Bendig, 1975) with skiers from the German Olympic Alpine Ski Team. The figures for the **D Area** of C6 calculated from the frontal area at 30m/s represent 0.132m$^2$ in P1, 0.104m$^2$ in P2 and 0.101m$^2$ in P4.

It can be seen from a comparison of the aerodynamic performances of C6 both in 2010 and 2011 with those of the non-disabled athletes from the 1970's that the performances were very similar. C6 achieved her lowest $\mathbf{C_D}$ (0.151) at 20m/s in P3, and equally in 1975, the lowest $\mathbf{C_D}$ figure (0.150) was produced when performing a similar posture using the same operational range of speeds and an equivalent estimated frontal area.

**Postural Evaluation**

**Analysis of Lateral Photos**

It should be noted when analysing the postures performed by C6 over the two campaigns that she did not carry out testing at 10m/s in T2. In P1 in 2010, the volunteer carried out the required position with a slight lowering of the hips and the body held a little further back in relation to the feet when moving on from the 2$^{nd}$ stage. Still in P1 but in 2011, C6 performed the position in a more consistent manner, bending the knees slightly with the advancing stages and lowering the hips. Comparing the performed postures between the two campaigns, a fundamental alteration in body position can be seen (in 2011, C6 projects more to the front)

In 2010 for P2, it was observed that C6 showed minimal variation in the height positioning of her hips, and likewise in 2011 C6 once more showed consistency in the execution of her test posture with minimal variation in hip height. When comparing postures between the two campaigns we can see that the position adopted by C6 in 2011 was quite different from that of the previous year, with greater knee flexion bringing the hips lower and holding a more grouped together position than in 2010, making clearer the reason for the difference in results found between the two campaigns.

In 2010 for P3, C6 performed the stages in a very consistent manner, other than advancing the arms further forward in the third stage in relation to the second. In 2011, C6 carried out the entire sequence without presenting significant postural alterations. In a comparison between the postures performed over the two campaigns, it is clear that the athlete maintained a different posture in 2011 to the one adopted for P3 in 2010. Greater flexion of the knees occurred and her body was pulled together tighter into a more grouped position than in 2010. This change in posture will explain the difference in results found between the two campaigns.

**Analysis of Frontal Photos**

An analysis of the postures held by C6 in the frontal plane for the 2nd campaign only, highlights that in P1 the volunteer was able to carry out the posture with her eyes directed forward, forearms at the height of the knees and the legs naturally spaced and side by side. Little difference is seen between P1 and P2, with only a closer grouping together of the trunk with the legs, creating a smaller and more compact silhouette diagram. A greater difference can be seen in the performed position of  P3. The forearms are higher and the ski-pole can no longer be seen. Despite the silhouette diagram produced by the body being the least area for the 3 positions performed, the D and $C_D$ values produced are technically equal, leaving it down to the skier to decide which position is more comfortable to perform.

**Questionnaires**

The questionnaires applied in the 2nd campaign provide exact details of the beginning of the training season (May) for C6 and the overall progress of her training year. C2 trains on a daily basis throughout the year and on some days carries out two different forms of training session. In the period from March to June after the competitive season has ended, C6 conducts 10 weekly workouts with an emphasis on physical work (60%) and 2-4 additional training sessions focused on technical work (40%). In the period from June to September, the strategy employed in the previous quarter is continued but increasing the volume of physical work (80%) centred more on strength than aerobic work at a ratio of 7 to 1, and being supplemented with outdoor work. The volume of training grows slightly in the period of Sept/October to December with the number of training sessions increasing to reach 11-13 weekly sessions. The division of the weekly training remains virtually the same with the emphasis being on physical work (60-70%) and additional sessions (30-40%) focused on technical work. It is the technical training that consumes the most time and can extend up to 4h in duration. The competitive season takes place in the months from Dec/January to March and C6 reduces drastically her volume of training in this period, seeking to divide her workload so that she can dedicate 40% of her time to physical workouts and the remaining 60% to technical and outdoor workouts.

Her best results at the World Alpine Skiing Championships 2011 (Sestriere/ Italy) were 1st place in the Slalom and Down Hill competitions, 2nd place in the Super Combined and 3rd place in the Super-G races, and as such, C6 showed herself to be effective in not only the races requiring speed but also those requiring agility. It is important to highlight that the athlete did not suffer any accident or injury during the World Championships.

Despite being young, C6 has a reasonable amount of international competitive experience and has awareness of her physical condition and high self esteem. From her questionnaire answers related to the WT tests it appears that C6 felt she was able to perform safely and comfortably. Although she did not perform the initial stages in the 1st campaign, she thought the level of demand of the aerodynamic test to be relatively hard. She believes the test results to be important but does not know exactly how they can be incorporated into her performance and training routine. Her completion of the post-test questionnaire confirmed what she had stated in the pre-test questionnaire

It can be seen from responses related to the investigation conducted at the Physiology Laboratory that C6 was able to safely perform the test, although it was observed that she did not do so as comfortably in the 1st campaign. However, in the 2nd campaign she was able to perform for more time. According to her self-perception and from a respiratory point of view, she could carry out the test well and comfortably. She believes these results to be more important than those found in the WT in terms of her performance and training. She also believes that her training has been adapted to take into account a number of improvements from the sessions. In the post-test questionnaire, C6 confirmed her statements made pre-test and believes that she is currently in a period of very good physical fitness.

## 2.7 Case number 7/ Volunteer (C7)

The seventh case is a male athlete born on 02/09/70. He has a disability classification of LW 5/7-2, being a skier with amputation to the right arm and a deficient left hand (dysmelia). He skis without the use of ski-poles, prostheses or orthopaedic appliances. C7 has participated in Alpine Skiing since 1990, having taken part in both international competition and those organized by the German Ski Federation. He is an active member of the German Alpine Ski team (*DPS*), having competed in Paralympic games from 1992 to 2010. To date, he has won 16 gold, 4 silver and 2 bronze medals in these competitions over the length of his career. As can be seen from Table I (p.78), C7 is 185cm tall and weighed 86kg at his last evaluation, giving him a Body Mass Index of 25.13kg/m$^2$.

### 2.7.1 Tests

The athlete C7 took part in only the first campaign of this research study. He was the seventh volunteer to carry out the ergometric testing, which he completed on an ergometric bicycle. He was the second athlete to be evaluated in the wind tunnel. The volunteer had experience prior to the campaign of 2010 of completing a bicycle ergometry test. In T1, C7 followed the standard protocol until he uncharacteristically stopped the test due to a lack of motivation, resuming it seconds later, before ultimately ending the test due to fatigue. Test T2 took place in the wind tunnel and although athlete C7 had no previous experience of taking part in such an environment, he was able to carry out the task with some consistency, although he did not complete all three positions for the wind speeds indicated.

**Cardiopulmonary Test**

**Preparations/ Control/ Immediately before/ During /After the test /Recovery**

The initial load for the test was 100W and this was conducted in accordance with Hollmann's protocol. The blood sample collected before the test showed a lactate acid concentration of 0.7mmol/L. The cardiac electrical activity of the volunteer was monitored closely during testing, together with the consistency of the recorded physiological values to ensure that none of the monitored recordings showed any warnings signs. The test session was brought to an end at the request of the athlete, having reached his limit of endurance. New blood samples were collected immediately at test end, and again 3min. and 5min. after the end, with these values being presented in Table 1. The athlete was asked after the test about the nature and intensity of the limiting symptoms, with the replies being recorded on a standard form. Routine post-tests were carried out during the recovery period to ensure that both ECG and systemic blood pressure measurements returned to normal before releasing the volunteer and bringing the test session to an end.

**Results of Cardiopulmonary Test 1**

The volunteer was required to pass a pre-test before being allowed to take part in the actual testing session. The HR and lactate acid levels found, as well as the load values used in the ergometric testing are detailed in Table 22 and in Figure 96.

**Table 23 – Results of Test 1 for Athlete C7**

| Time (min) | $P_N$ (Watt) | HR (bpm) | LA (mmol/L) | RPM |
|---|---|---|---|---|
| 0 | 0 | 58 | 0.7 | |
| 3 | 100 | 84 | 1.2 | 73 |
| 3 | 150 | 98 | 1.2 | 71 |
| 3 | 200 | 118 | 1.6 | 69 |
| 3 | 250 | 128 | 2.3 | 67 |
| 3 | 300 | 143 | 3.2 | 62 |
| 3 | 350 | 159 | 6.4 | 62 |
| 3 | 400 | 174 | 11.1 | 70-74 |
| | | | | |
| 1 | | 169 | 13.2 | |
| 3 | | 134 | 13.2 | |
| 5 | | 103 | 13.8 | |

$P_N$ – Mechanical output, HR - Heart Rate, LA – Lactate, RPM – Revolutions per minute.

**Figure 96 – Results of Test 1 for Athlete C7**

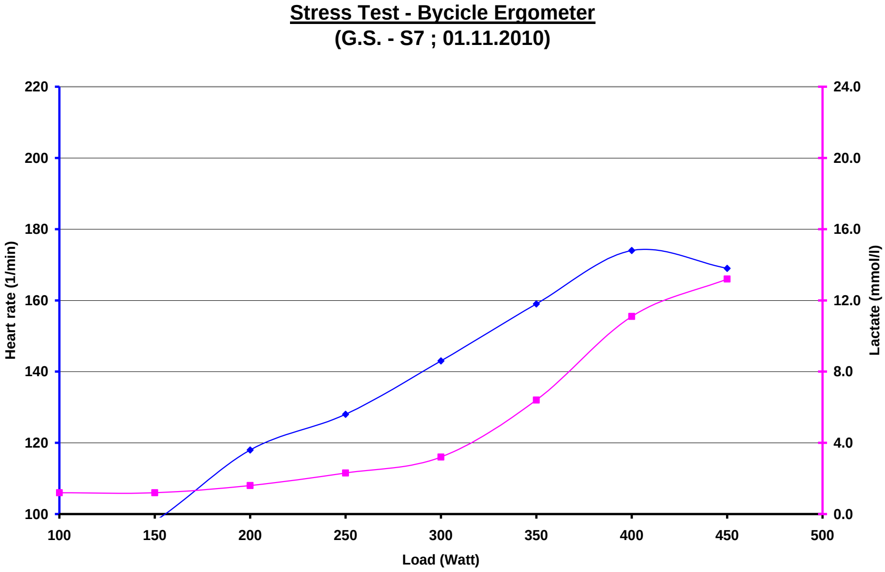



**Figure 96**: Performance curves for HR and Lactate levels in relation to stage of testing for evaluation conducted in 2010

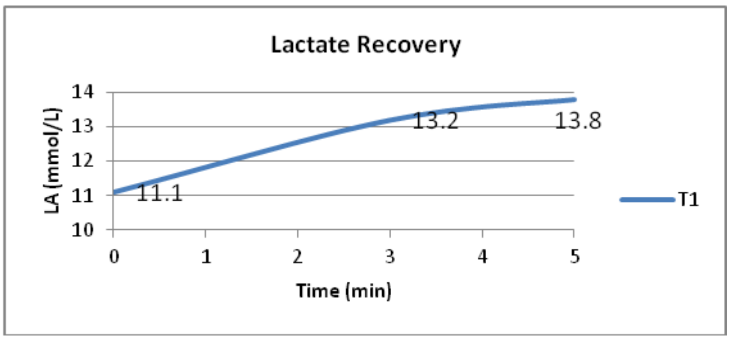



**Figure 97 –** Physiological data (lactate) after Test 1 conducted in 2010.

The athlete was able to carry out the test in accordance with the protocol for this campaign with progressively increased loads. From a motor point of view, he maintained an almost constant rate of rotations per minute as the test phases advanced, with a gradual reduction in the frequency occurring in the final 3 stages as compared to the first 3. The highest load achieved by the athlete in the test was 400W when carrying out the seventh stage. C7 presented a lactate reading of 11.1mmol/L immediately after the test end, followed by a reading of 13.2mmol/L from the second blood collection after 3 minutes and 13.8mmol/L from the 3rd collection after 5 minutes (Figure 97). As can be seen in Table 22, the maximum HR reached in T1 was 174bpm, measured immediately after the test end. It is important to note that the athlete did not use footwear with straps in this campaign.

**Aerodynamic Test**

**Preparations/ Control/ Immediately before/ During /After the test /Recovery**

C7 was the athlete to spend the least amount of time in the WT test section by virtue of the fact that he did not complete all of the predetermined standard positions. The volunteer was monitored closely during testing in relation to both his personal safety and performance of the test positions to be carried out. No contact occurred during testing between the support platform for the skis and the WT floor.

**Results of Aerodynamics Test 2**

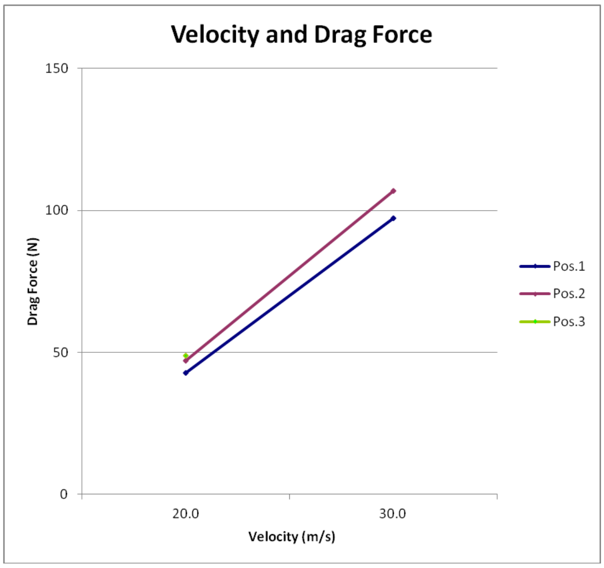
In this campaign, C7 was able to perform those positions that he actually carried out in accordance with the protocol, as can be seen in Table 23. In terms of coordination, he could perform, maintain and repeat the requested positions with precision. The largest **D** presented by him was 106.88N in P2 at 30m/s. His lowest **D** value for the test was 42.72N in P1 at 20m/s. The largest $\mathbf{C_D}$ presented by him was 0.413 (0.207) in P3 at 20m/s. His lowest $\mathbf{C_D}$ value for the test was 0.360 (0.180) in P1 at 20m/s.

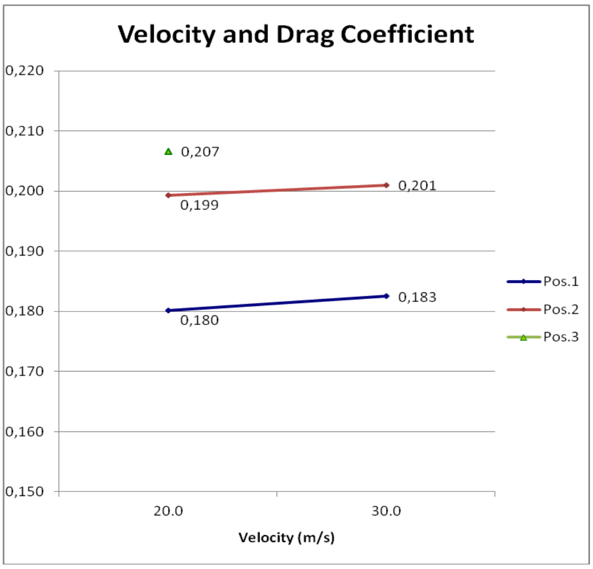
**Table 24 – Wind Tunnel Test Data for C7**

| Pos. | Velocity [m/s] | Drag Coeff. [-] | Drag Force [N] |
|---|---|---|---|
| Ref. | | **2010** | **2010** |
| 1 | 10.0 | | |
| | 20.0 | **0.360 (0.180)** | **42.72** |
| | 30.0 | 0.365 (0.183) | 97.34 |
| Ref. | | | |
| 2 | 10.0 | | |
| | 20.0 | 0.399 (0.199) | 47.01 |
| | 30.0 | 0.402 (0.201) | **106.88** |
| Ref. | | | |
| 3 | 10.0 | | |
| | 20.0 | **0.413 (0.207)** | 48.92 |
| | 30.0 | | |

Obs.: The values were obtained from the estimated frontal area of $0.5m^2$ of the athlete in 2010. The numbers highlighted in bold are the maximum and minimum values found in each session.

It can be seen from the photographic records that follow that the values presented with respect to each photo have already been corrected in order to enable construction of the graphs.




**Figures 98 and 99 –** Performance curves for **D** and **CD** according to test stages performed in 2010.

**Description of Positions**

**Lateral Photos Recorded during the WT Experiments**

*P1 – 20 m/s* – In the photo (T2P1S2), it can be seen that the athlete is in a crouching position with knees bent at an angle greater than 90º, with the body bent over at the hips, and the hips positioned slightly higher than the shoulders. The trunk is supported over the thighs, with the arms resting to the front of the knees, presenting a centralized and balanced position. The elbows are below the knees and bent at an angle greater than 90º. The left hand is to the front of the face and the neck extended, with eyes directed to the ground.

*P1 – 30 m/s* –In the photo (T2P1S3), the performance of the athlete is very similar to that presented at 20 m/s. His body is presented in a central, balanced position with knees being bent a little further and the hips virtually level with the shoulders.

**Figure 100: Position 1 – "Egg form" Position**

20 m/s – photo T2P1S2 – Drag Coeff. 0.360

30 m/s – photo T2P1S3 – Drag Coeff. 0.365

*P2 – 20m/s* – In the photo (T2P2S2), the athlete is seen on foot in a crouched position, leaning a little to the front and with his weight shifted further forward. His knees are bent (approx. 90º), with hips bent and held higher than the shoulders. The trunk is supported over the thighs, with the arms perpendicular to the floor but no longer being supported by the knees. The elbows are positioned lower than the knees and bent at an angle greater than 90º. The hand is held in front of the face, and the neck extended with the eyes directed to the floor.

*P2 – 30m/s* – In the photo (T2P2S3), the athlete is reproducing a position almost equal to that assumed at 20m/s, however, there is a slight alteration in the body position, with its being held a little further back and with a corresponding shift in the weight also. The knees are bent a little more, bringing the hips a fraction lower.

**Figure 101: Position 2 – Run Position**

20 m/s – photo T2P2S2 – Drag Coeff. 0.399

30 m/s – photo T2P2S3 – Drag Coeff. 0.402

**Figure 102: Position 3 – "Attack" Position**

20 m/s – photo T2P3S2 – Drag Coeff. 0.413

*P3 – 20m/s* – In the third position (photo T2P3S2), the athlete's body is held the furthest forward of all the three positions performed. His trunk is bent over the thighs but not as hunched over as in the previous stance. The arm is at slightly more of an oblique angle to the floor, with elbow bent (approx. 90º), extending his hand to a position in advance of his head. The knees are flexed (approx.

90º) and the hips are the highest point of the athlete, being a little raised above the horizontal line of the head. This combination results in the spinal column being at its straightest for all the positions performed.

The general results of the anthropometric evaluation, the treatment of the photographic records, and the questionnaires and field notes completed by the athletes for both campaigns have now been presented. We would now like to put forward, in addition to the individual results presented in relation to tests performed on the ergometric bicycle, and in the wind tunnel, a follow-up of the individual analysis by means of a discussion for the athlete in question.

### 2.7.2 Human Performance - Discussion

**Objectives Assessment**

The evaluative process was conducted with the intention of increasing the range of information and understanding about the performance structure that affects the world of this athlete from the *DPS*. It also aimed to analyse his results, comparing between his own performances and with those of his fellow team members, as well as with the results of non-disabled athletes from the sport of Alpine Skiing.

This athlete, born in September 1970, has a long history of training with the *DPS* and competitively participated from 1992 until 2010 in the Paralympic Winter Games, winning 22 medals including 16 gold, 4 silver, and 2 bronze in the standing class competitions. At times during the course of these experimental studies it was found that his personal life and appointment schedule directly interfered in the time required for testing and this eventually adversely affected his motivation for continuing fully with the evaluation. Despite not having participated in the 2$^{nd}$ campaign, which interfered with the collection of quantitative and qualitative data and also resulted in frontal photographs not being taken and questionnaires not being completed, the results that were obtained were interesting and respectable for this competitive sport, as well as for the scientific community.

**Anthropometric Assessment**

The anthropometric assessment conducted of C7 showed his body weight to be 86kg and his height as 183cm, enabling his body mass index to be calculated as 25.13kg/m$^2$. This falls within the range of values considered to be normal, according to "The Practical Guide: Identification, Evaluation, and Treatment of Overweight and Obesity in Adults" (National Institutes of Health, 2000).

**Physiological Assessment**

The spiroergometry evaluation was carried out to check the fitness condition of this athlete without exposing him to risk. It produced coherent results for 80% of the test, however not for the entire test as the athlete interrupted his performance towards the end without apparent reason. He resumed again just a few seconds later in a more intense manner than had been the case in the previous few moments of his test. Even so, it can be said that C7 continues to show good physical fitness, although it was not possible to verify his $\dot{V}O_2$ values.

Only an evaluation of his mechanical efficiency could be taken into account for the purposes of assessing the functional capacity of C7. The athlete was able to advance to and complete the 7th stage (400W) of his evaluation, with this being significantly different from the test outcomes of the wheelchair users on the treadmill, or even when compared to his colleague C6 who competes in the same competitive category.

It can be seen by comparing the $HR_{max}$ recorded for C7 with his pre-determined $HR_{max}$, according to the Karvonen formula (Robergs 2002, Policarpo 2004), that he reached a submaximal HR in T1. Follow-up measurements taken 3 minutes after test end show his HR to be less than 140bpm (134bpm), indicating good cardiovascular fitness.

Increases in values of lactate concentrations for C7 were recorded in the first 5 minutes of the post-test recovery period. The recovery response of the volunteer was gradual, with the test-end lactate concentration value being surpassed by higher values in the subsequent readings. Even taking into account these post-test readings, it can be said that the recovery of the athlete was satisfactory.

**Aerodynamic Evaluation**

The aerodynamics evaluation was intended to take account of the amount of drag produced by this athlete and generated innovative results without exposing C7 to risk. The athlete produced a high-level performance in the WT, adopting the 3 different positions that he believes to be important for his progress in the alpine ski competitions in which he participated. The readings obtained from the athlete were quite consistent, as can be seen in Table 23 and in Figures 98 and 99.

The analysis of the **D** performance for athlete C7 shows that he was able to produce a value of 106.88N for the posture that offers the most resistance for the stand-skiers, which is P2 at 30m/s. The athlete was always able to produce an improved performance for this posture than for the others, as can be verified in Table 23 and Figures 98 and 99. The analysis of the $\mathbf{C_D}$ values encountered in the experiment also show consistency in the results as there was an increase in the $\mathbf{C_D}$ figures, albeit slight, for all the positions performed following an increase in wind velocity.

It was not possible to take the frontal photographs of C7 and consequently, the calculation of frontal area for the athlete could not be made, nor the more accurate $\mathbf{C_D}$ value according to the frontal area. Despite this, some comparisons are possible with study data collected in the 1970's (Bendig, 1975) from research involving skiers of the German Olympic Alpine Ski team and also with studies conducted by Watanabe (1977) in Japan. In a comparison of the aerodynamic performance of C7 with that of the non-disabled athletes from the 1970's, it can be noted that one of the performance factors of C7 was inferior to results shown by the athletes who took part in the research carried out in the 1 metre WT in Gottingen. The athlete achieved his lowest $\mathbf{C_D}$ (0.180) figure in P1 at 20m/s, whereas the lowest $\mathbf{C_D}$ figures achieved by the athletes from 1975 in tests conforming to the same speed range and similar postures are presented in Table 24.

**Table 25: Test Data from Experiments conducted by Bendig (Germany, 1975)**

| **Athletes** | M.V. | P.F. | S.P. | A.G. | R.T. | R.J. | S.F. |
|---|---|---|---|---|---|---|---|
| $\mathbf{C_D}$ | 0.122 | 0.162 | 0.178 | 0.153 | 0.168 | 0.147 | 0.167 |

Conversely, in a comparison of aerodynamic performance with that of the non-disabled athletes who also conducted such tests in the 1970's, it can be seen that one of the performance factors presented by C7 was superior to those of the athletes who took part in WT testing carried out in Japan, as verified in Table 25. Athlete C7 obtained lower **D** values in P2 both at 20m/s and 30m/s, whilst conducting experiments with the same range of speeds and similar postures as performed by the athletes in 1977.

**Table 26: Comparison of Test Data from Experiments conducted by Watanabe (Japan, 1977) with Study Data presented by Vinagre (Germany, 2010).**

| **Pos.** | **Velocity [m/s]** | **Drag Force [N]** | **Drag Force [N]** |
|---|---|---|---|
| Ref. | | **1977** | **2010** |
| 2 | 10.0 | | |
| | 20.0 | 66.84 | 47.01 |
| | 30.0 | **118.58** | **106.88** |

**Postural Evaluation**

**Analysis of Lateral Photos**

It should be noted for the analysis of postures held by C7 during T2 that he did not perform testing at 10m/s for any of the positions adopted and also did not perform P3 at 30m/s. It is interesting to highlight that unlike the sit-skiers, C7 evolved a fluid change in positioning over the course of the test, beginning with a very centralised body position supported well over the feet and limbs grouped closely together (Tuck Position - P1), and progressing through to a final body position held further forward and limbs being less tightly grouped (Attack Position - P3), setting a series of 3 different positions for evaluation and being able to establish a relative consistency in their performance.

The athlete was able to carry out and repeat the P1 posture at both wind speed stages with his neck extended, back curved and trunk supported over the thighs. The buttocks were maintained at the same height as the head, knees flexed (approx. 90º), left arm and axilla tucked closely in front of the knee, elbow flexed (more than 90º) and hand positioned near the front of the face. The biggest performance difference from one stage to the next was the hip position, which was slightly lower at 30m/s than for the previous wind speed due to the knees becoming a little further flexed.

C7 was also consistent in his performance of P2 over the two wind speed stages. Moving on from P1, the hip position was raised higher and the trunk held less tightly against the thighs. The arm and axilla moved slightly to the front of knees that were in turn, bent at an angle of more than 90º. The biggest difference in performance from one stage to the next was the body position being held slightly further forward than had been the case at 20m/s.

Shifting from P2 to P3 involved C7 adopting a position where the hips were held at their highest point of his performance, with a straighter back and trunk no longer being in direct contact with the thighs. The arm and axilla moved further to the front of knees that were flexed at an angle greater than 90º, with the arm extended further forward and elbow bent (approx. 90º), positioning the hand a distance in advance of the face.

# IV. FINAL CONSIDERATIONS, CONCLUSION AND RECOMMENDATIONS

## 1. Review of the main points of the Achievements

### 1.1 Sit-Skier Assessments

#### 1.1.1 Cardiopulmonary

The athletes were unanimous in stating that the position they preferred and felt more comfortable performing for the cardiopulmonary evaluations was one where the trunk was held upright. As the physical load increased during testing, however, it was necessary for the athletes to bend their trunks forward in order to maintain their performance. This alteration in posture interferes directly with their respiratory function, in their biomechanical performance, and in their ability to meet the demands required by the test, ultimately reaching a level whereby the athlete is no longer able to sustain either the energy demand or the motor/postural function, due to the increasing load. In some cases, as seen during testing with volunteers 2 and 3, the alteration in posture interfered directly in their postural comfort and motor ability to continue with testing.

#### 1.1.2 Aerodynamic

The responses regarding preference for the posture providing most comfortable for the aerodynamics evaluation carried out with all the sit-skiers were more divided. Volunteers 1 and 2 preferred and felt more comfortable when positioned with the trunk flexed at 40º (P3 and P4), whilst C3 chose a more perpendicular position (P1) and C4 preferred a more intermediate position (P2). Volunteer 5 did not participate in the study when the questionnaires were being completed. The position P3 carried out in tests T2 and T3 over the two campaigns by the *DPS* athletes was performed with ease, comfort and precision, and is an important position for the race competitions. It was only required for this position to be maintained for a timescale of 30 seconds in testing, however, the same time as for the other positions.

It is worth noting that even in favourable conditions, the down force on the athlete increases as the wind speed increases. This necessitates that greater muscle contraction is made by the athletes for those muscles involved in maintaining the required posture for each position. This increased effort is assisted in P1 by the support offered from the back of the sit-ski, while in P3 the airflow that passes over the backs of the athletes partially helps to maintain posture. The greatest effort is required in P2 where the trunk position of the athlete is maintained in an intermediary position or in P4 where the sit-skier performs with the outriggers held directly to the front of the body. It also became clear in the aerodynamics test that the volunteers need to maintain their postural stability and ability to manoeuvre with precision, whilst also continuing with the isometric contraction of the muscles. Any alteration in position that occurs after setting the desired posture causes changes in drag and thus interferes with the athlete performance.

Another interesting aspect associated with this assessment is that despite the athletes involved having spinal cord injuries at different levels (T12, T5, T5, L2, T8), they were able to hold with ease the postures (P3 and P4) that offer the least air resistance in respect of their competitive sport. Conversely, these athletes experienced discomfort in breathing and in exercising for a long time period when participating in the ergometric treadmill evaluation using a WC, which leads us to consider the need for possible forms of training focused on developing these capabilities.

**1.2 Stand-Skier Assessments**

**1.2.1 Cardiopulmonary**

In the cardiopulmonary assessment it was noticed that both the stand-skiers remained with an upright trunk in the initial stages, but the athletes felt the need to bend the trunk forward and support the forearms on the upper part of the hand grips of the ergometric bicycle as the physical load increased. Volunteer 6 (C6) reported that she preferred to keep her trunk upright and felt more comfortable in that position. Volunteer 7 (C7) did not participate in the study at the time the questionnaires were being applied. Even with congenital malformations (C6 and C7) and a right arm amputation (C7), both volunteers are regarded as "innate" endurance athletes and distance runners among people with physical disabilities (Innenmoser, 2012). The sport specific performance of these athletes is closely related to their lower limbs, to their body balance as a whole, and also to the performance of the trunk and upper limbs, with C6 using one ski-pole for the sport and C7 using none.

**1.2.2 Aerodynamic**

The freedom given to the stand-ski volunteers by the evaluator to execute the progression of the 3 positions as they wished in the aerodynamics evaluation resulted in two distinct performances from the athletes. C7 appeared to have a better understanding of what was required for the test, whereas it seemed that C6 was uncertain as to the sequence of positions to be accomplished. Furthermore, from the questionnaire completed in T3, it was possible to see that P3 would have been the posture preferred by C6 and the one that provided the greatest comfort.

Both athletes chose not to carry out the first wind speed stage of the evaluation despite being in favourable conditions and in addition, C7 chose not to carry out the third speed stage in P3 of the first campaign. The positions that were conducted, however, according to the perception of the evaluator were performed with ease, precision and comfort; although all of the postures were requested for only a short time period (30s) and so would not have left the volunteers in a state of exhaustion. The order of the positions chosen by the stand-skiers in which to conduct the test was to begin with the one offering the least resistance (P1), whereas P3 would be the position offering the greatest resistance. It became clear in testing that the stand-skiers present a more mobile surface area of exposure to airflow and, as a consequence, they are more subject to drag changes caused by an inability to maintain a stable position for the required time, which generated interference in their performance. Another interesting aspect of this evaluation was that each of the two stand-skiers produced a different body reading for the posture that offers the least wind resistance for their sport, based on their own disability and perception.

A further distinction between the tests performed by the sit-skiers and the stand-skiers in relation to the leg work required for the sport became apparent. In the case of the sit-skiers, this work is accomplished by the mechanical shock absorbers coupled to the underneath of the monoski seat, and in conjunction with the use of the trunk muscles. This differs in the case of the stand-skiers, who need to use the contraction of the leg muscles in order to maintain performance of each posture, with the work being constant and varying in intensity depending on the position and terrain. Even in the posture producing the smallest exposed surface area and offering the lowest wind resistance, the required contraction of the leg muscles remains constant.

## 2. Final Considerations

The performance of alpine skiers is affected by a number of factors (Leach, Fritschy, Steadman, 1994). It could be seen when considering the individual factors, physical conditions and physiological loads applied in the two evaluative campaigns and from the aerodynamics tests of the *DPS* athletes, that there exists a paradox between what can be seen from the experiments conducted in the Exercise Physiology Laboratory (cardiopulmonary evaluation) and those performed in the Wind Tunnel (aerodynamic evaluations). Although the athletes were subject to loading in both scenarios, they were applied in opposite directions, which demanded quite different responses from the volunteers.

Although the technique of evaluation itself has not been the subject of direct discussion in this study, it can be said from the analysis of aspects related to the physical fitness of the athletes as verified by cardiopulmonary testing, and motor (posture maintenance) aspects as verified both by physiological and aerodynamic testing, that it has benefited the results of the athletes by improvements experienced in their physical fitness. Tactical aspects have also benefited as the performance structure has been enhanced as a result of the conducted tests, as can be seen in Figure 1.

Figure 1 presents an adapted diagram from Wippermann (2012) of the performance structure for Paralympic Alpine Skiing created by Jonath and Krempel (1981). The extent of the form of performance structure currently directed at this sport can be seen and this could be become more specific still with the inclusion of "new" factors evaluated in our study. The structure of the diagram presented by Wippermann remains, although it has been adapted to follow an order of importance related to the tests from this study.

The factor that can be considered least linked to this evaluation process is in pale blue. In darker blue are factors not directly measured but directly affected by the evaluations performed. In green are the factors that were, at different levels, measured and that are affected directly by the assessments carried out in the proposal presented to the volunteers. In yellow are the tests that brought greater specificity and innovation to the performance structure in this sports category.

Spiroergometry, which can be considered part of the performance structure for this sport, is influenced by individual physiological elements. The aerodynamic testing, which was included for the first time as part of the performance structure for handicapped Alpine Skiing, showed that other elements can be evaluated (EMG, body temperature) from the proposed environment, the materials used in the athlete evaluations and the level of individual safety found in this sport.

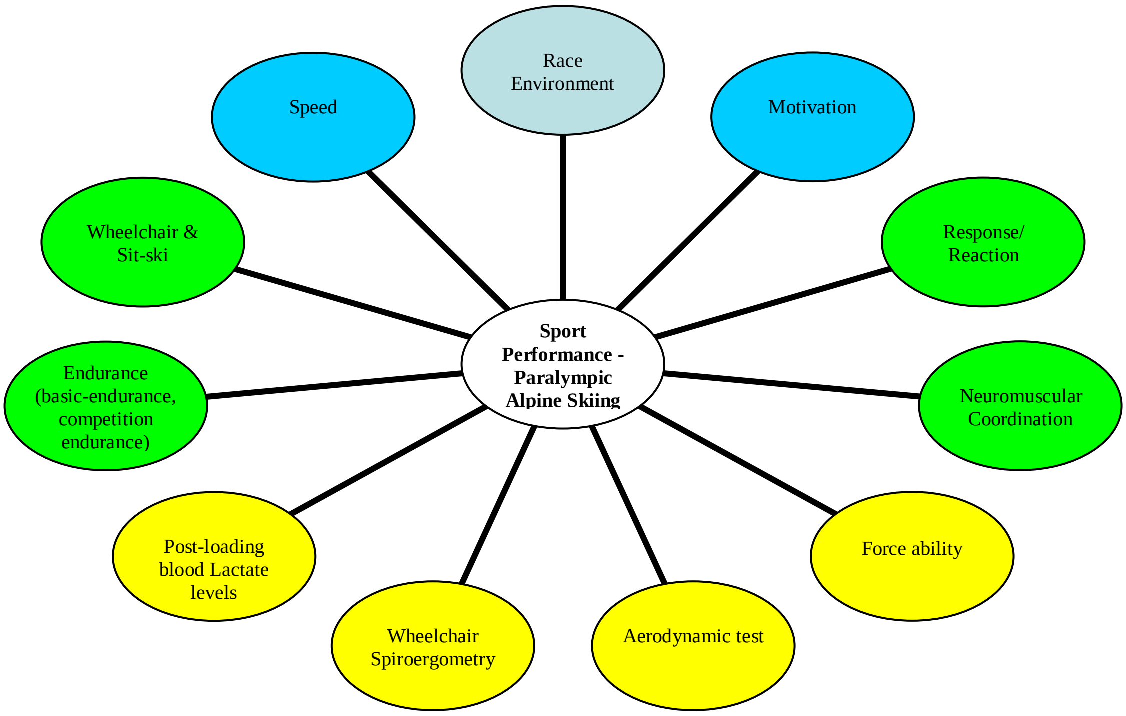



**Figure 1:** Performance structure for Paralympic Alpine Skiing, according to Jonath and Krempel (1981) as presented in the thesis of Wippermann, adapted for order of importance and tests conducted in this study.

The development of suitable materials for this sport and adapted for disability certainly plays an important role in the athlete performance and they may even benefit from the information derived from the assessments carried out, although this was not the focus of the study.

## 3. Conclusion

The evaluations made with the sit-skiers and stand-skiers of the *DPS* were intended to produce results for analysis not only of the individual athletes but also an analysis in relation to other team members, with the aim of establishing parameters for comparison. Each of the athletes voluntarily agreed and showed an interest in taking part in this research and testing, although all coming from different backgrounds and having varied histories and routes taken to achieve their results throughout their performances as international competitive skiers.

Volunteer 1 (C1), who is one of the most experienced athletes from the team, obtained the second best performance in the 1$^{st}$ campaign and the best performance in the 2$^{nd}$ campaign. His test results were as good as those of the gold medallist from this sport (C5), whose results served to guide the technical team in the type of training that should be conducted.

Volunteer 2 (C2) is the only female member of the sit-ski team (at least in the period the study was conducted) and she has already achieved significant results in competition, despite having only a recent history with the team. Although the results obtained for her in the study have been very interesting, making a comparison between them and those of the other athletes proved difficult, due to issues related to gender and age. Even so, when comparing only the physiological values (e.g.$\dot{V}O_2$ max

1768mL/min in T4) obtained through her assessment using a treadmill and WC, with those of the female stand-ski athlete from the team who used an ergometric bicycle (e.g. $\dot{V}O_2$ max 2366mL/min in T4), it is clear that despite being athletes of the same gender and with similar ages, there is disparity between the individual characteristics and profiles of the athletes and the evaluation methods used, and the results cannot be directly compared. It can be said that C2, proportionally, was the athlete that evolved most from one campaign to the next.

Volunteer 3 (C3) is the newest member of the *DPS*. His performance in the 1st campaign was modest in both tests. His performance, however, in the 2nd campaign was much improved in the aerodynamics test, presenting superior results to the 1st campaign for all the positions, except P4.

Volunteer 4 (C4), who does not currently present a significant competitive background, did not carry out the test T1 on the treadmill as he was found to have a cold and his results would have suffered as a consequence. In addition, it was not deemed necessary to expose him to unnecessary risk. It is difficult to analyse his performance as the tests in which C4 did participate were subject to differences in material test conditions (sit-ski, ski suit) and comportment conditions (postures performed) in tests T2 and T3. Despite this lack of uniformity, the absolute values encountered in the aerodynamics tests conducted by C4 were as good as the results from the gold medallist from the sport (C5).

Volunteer 5 (C5) has a brilliant record in the Alpine Ski sport and had, proportionally, the best performance of a team member in the 1st campaign. These findings lead us to believe that the result achieved by the volunteer is due to the combination of a superior biomechanical performance (Niklas, Fuhrmann, Hottowitz, 1994; Vanlandewijck, Theisen, Daly, 2001), good aerobic conditioning, and especially the experience to understand the course of cardiopulmonary testing (Niklas 1987, 1989; Veeger, Hadj Yahmed, Van Der Woude 1991; Bhambhani 2002).

Volunteer 6 (C6) is the only female representative of the stand-ski team, which makes it difficult to compare her results with the other team members. The athlete performed all tests with dedication, which allowed for improvement in the evaluation process for the evaluator and for the athlete personally. A comparison was made between the physiological parameters of C6 with those of C2 (female sit-skier), although they are classified in completely different disability categories. It was clear from this, however, that C6 is close to reaching a developmental plateau as despite there being an evolution in her performance from one evaluation to the next, it was of a small proportion, whereas when looking at the evaluations completed by C2, one can see that there still exists potential for improvement both in the physiological and mechanical performances.

Volunteer 7 (C7) has a history of winning multiple championships within the sport being evaluated. He easily completed both tests in the first campaign despite lacking concentration and availability of time for T2. His performance in the ergometric testing in the 1st campaign could have been better had he not inadvertently interrupted his performance towards the end, but despite this, his test results were fairly good. C7 is the only male representative of the stand-ski team to have participated in this experiment, making a comparison of his results with those of the other athletes incompatible. Although it is not possible to make a direct comparison of the data for C7 from the 1st campaign with the results of athlete C6, the data was placed side by side to observe their individual performances. The values found for the spiroergometry test obtained using a stationary bicycle ergometer show that the performance of C6 in the test itself was better than the performance of C7 (performance curve, recovery), although the athletes differ in gender, age and disability classification. It is, therefore, apparent that the evaluation methods used are capable of producing significant data for each athlete, enabling individual training strategies to be established for the development of exercises for the upper body in the case of the sit-ski athletes, and the full body for the stand-ski athletes.

**4. Recommendations**

In order to improve the athlete performance for both sit-skiers and stand-skiers (Vanlandewijck , Thompson, 2011), especially when assuming a trunk position with greater forward flexion, it becomes necessary to develop a training plan focused on the maintenance of posture and respiration in positions: where the thoracic volume is physically reduced; where most demand is put on the muscles involved in respiratory mechanics; where the environment itself requires both these conditions simultaneously. In the tests performed by volunteers with the more severe disabilities (e.g. C2) it can be seen from one evaluative campaign to the next that their respiratory response endured longer as their postural stability improved, thus presenting a qualitatively superior performance in T4 in relation to T1.

It is believed that in some cases (C1, C5 and C6) and for differing reasons, the athletes need to continue altering their body proportions (body compartments). For athletes C1 and C6, reducing their body fat percentage whilst raising their lean body mass percentage without reducing their weight, would bring changes in the performance of their sport. Whilst in the case of volunteer C5 whose objective will no longer be participation in high performance competitions, the purpose of this action would lie in the prevention of future metabolic complications. The loss of muscle mass in older athletes (C5 and C7), together with the ending of professional competitive activities makes the continuance of muscular endurance work essential as a means for the maintenance of lean body mass.

The physical training of those athletes remaining on the competitive circuit should not only include technical and tactical work, but also focus on aerobic conditioning and localized muscular endurance activities, with these being activities that fit well with the type of physical work skiers are subjected to during their races. In this line of work involving alpine skiers, specific systematic reviews and individual training plans play a decisive role in balancing the physical needs, techniques and tactics that every athlete requires, and the physical preparations must be adapted to take account of the specific motor responses given by the athlete and also to the stimuli generated by the racing terrain and by the activity itself.

The need for the improvement of exercises focused on the upper body, both for the sit-skiers and the stand-skiers, is apparent from the evaluation methods used and the data acquired. Not only should this information gained be applied to high performance sports and athletes from the elite sports world, but of equal importance is its application to the development and rehabilitation of ordinary citizens with disabilities, as well as disadvantaged members of our communities. Strength training is an essential component in exercise programs for any case of SCI (Rimmer, 1999). Maintaining the muscles of the upper body becomes very important for the performance of the necessary activities of daily routine. Stretching and flexibility exercises are also needed for the entire body to prevent contractures.

Aerobic training in its many different forms and activities is also recommended for the sit-skiers with the intention of increasing their metabolic rate and aerobic capacity. This training, traditionally performed using a hand cycle in the seasons suitable for outdoor work, can be compensated for in the less favourable climate conditions (autumn and winter) by indoor activities. Among these are water-based activities, which are very suitable for people with special needs and to which the study author attaches strong rehabilitative value and has the conviction that they are appropriate for the aerobic preparation of the alpine skier. Although swimming receives almost exclusively the credit for being the cardiovascular respiratory preparation of choice, it is by no means the only aquatic option that can be adapted for training skiers. Diving (apnea), watsu and canoeing all directly benefit the skills and abilities to be developed, trained and dominated by sit-skiers.

A variety of forms of aerobic training can be explored by the stand-skiers in order to optimize their aerobic capacity and obtain better results in competition, with their priority being training of the lower limbs in their physical preparations. Typical examples of outdoor race forms aimed at endurance are track and road racing or cross country racing that takes place over rough terrain. Training can also take place indoors at indoor tracks or using fitness academy treadmills, training centres or exercise laboratories.

Cycling can be practiced outdoors on cycle paths, indoors in gymnasiums, and even in fitness studios, and can also be a good training strategy. One very positive aspect to be highlighted in cycling relates to the body posture assumed by the athlete when performing this sport, with this being similar to the position required during alpine ski racing. It is, however, always important to be aware of the safety aspects of cycling and to not expose the athletes to unnecessary risk, especially when training outdoors or in a velodrome. Having a limb amputation and/or congenital malformation may affect the ability to gain support from the bicycle handlebars, as well as affecting the body equilibrium in relation to the bicycle (man-bicycle), which might increase the risk of falling.

Inline skating or rollerblading is another training option that can suit the specific work to be carried out with the legs to achieve a better sports outcome, with this sport also being suitable for practice indoors on a treadmill or outdoors in better weather conditions. One more form of sport to be considered by stand-skiers is cross country skiing, which can increase the level of specificity of the training environment and the use of certain equipment, however, without having the same type of movements needed by the alpine skiing

In reality, stand-skiers need a training plan focused on muscle strength and resistance, principally in the legs, and this will in turn provide postural maintenance, all the dynamics of the directional and shock-absorbing action performed by the legs and balance, as skiing will involve the partial aid of only one or even no ski-poles. Complementing this need for reaction/response that the skier must present during his performance, it is necessary to organise training involving proprioceptive training techniques and everyday strength and rehabilitation work.

It is also suggested that strength work be performed through techniques using resistance through springs as is found in Pilates, or through the use of resistance bands that allow a series of exercises to be performed whilst sat or in a WC. It is important to highlight in the Pilates method that many of the exercises are performed on the floor, allowing gravity to act perpendicularly to the joints and muscles involved. The exercises performed on the floor are suitable for strengthening the muscles of the trunk and lower limbs of the stand-skiers. The initial supine position used to carry out the exercises, affects the respiration performance and the muscles involved in Alpine Skiing, which works as a form of rehabilitation action, mainly for the postural changes caused by the consequences of a spinal cord injury (SCI). Table 1 shows the muscles, movements and functional goals related to the evaluated athletes from which one should develop the training on how to improve their capabilities.

**Table 1: Functional rehabilitation goals**

| Level | Key Muscle Control | Movement | Functional Goals |
|---|---|---|---|
| T1 – T5 | Various intercostal and dorsal muscles | Trunk support with no movement in the lower limbs | Daily routine, transfers and can drive adapted vehicles |
| T6 – T12 | Abdominals | Trunk control | Total WC independence and walking with orthoses |
| L1 – L2 | Psoas major and lliopsoas | Hip flexion | Walking with a brace and/or reciprocal walking device |

Functional rehabilitation goals relative to the neurological level of spinal cord injury. Rowley et al., (2000) *cited in* Nascimento.

## 5. Outlining Future Prospects

It has been shown and evidence exists that knowledge gained from the evaluation structure for Paralympic Alpine Skiing can be also be applied as a reference to other sporting forms for disabled participants. The combined information provided by the evaluation process carried out with the alpine skiers had a direct effect on the performance and safety of those involved. Measurement of physical conditioning is suitable for interpreting the physiological capacity of each skier, whereas the aerodynamics testing deals with the possibility of verifying the coordinative capacity of each skier, and the way they cope with their equipment, positioning and technique. In summary, this signifies that regular studies centred on disabled Alpine Skiing, even if carried out in an exercise physiology laboratory or a wind tunnel would be desirable for enabling a more focused training plan to be developed.

It is clear that the sport of Alpine Skiing, which was the target of this study, has an evaluation structure that is still in the process of development. It is a winter sport and as such, the competition period and specific *in loco* training requires the technical and physiological adaptation of the athletes to the environment. In contrast during the summer period, although the environmental conditions prevent the practice of the alpine skiing itself, it does allow the athletes to develop their physical abilities with a consequent shorter period of adaptation upon return to the competition season. It also enables the athletes to undergo both routine testing and additionally, tests that can bring forward new approaches to the performance of their skills and training, consequently enabling their physical, technical and tactical evolution.

In this study, the group of athletes investigated formed a very heterogeneous body, although all belonging to the same sport. Within these differences encountered among the group, the sit-ski team shares the characteristic of being composed exclusively of people with paraplegia, although to differing degrees. The application of an evaluation aimed at seeking analysis of a specific sports performance from a physiological, biomechanical and motor aspect has the initial goal of seeking the best results of the athletes in both competition season and during training. From a movement analysis perspective, it enriches the interpretation of information collected since each person evaluated will contribute one or more details of their own characteristics, requiring different strategies or solutions to be investigated by movement professionals.

It would be ideal for regular testing and monitoring of the continual development of an athlete to take place in order to seek their best performance. In this way, not only can their physical condition, individual regenerative capacity, and coordinative condition be verified, but it also allows aspects related to safety to be investigated. From the verification of lactate concentration levels reached and the respective regenerative performances, for example, it is possible to see how each athlete responds to adapted alpine skiing. Direct comparisons are not recommended. It would be more appropriate to carry out a continuous process of assessment of not only the athletes already evaluated, but all new cases also. It is therefore believed that a long-term longitudinal study would cover a wider spectrum of cases, further influencing the training process as well as having an effect on rehabilitation, prevention of injury and learning processes.

In addition, it would be interesting to continue with an extension of the current investigations by the inclusion of other performance diagnostic examinations of physiology and aerodynamic parameters. This could obtain more detailed results for each assessment in a particular environment, or could combine both assessments under the conditions of just one environment (e.g. wind tunnel). More specific studies for the sport of Alpine Skiing are currently being developed, but are only directed at able bodied sportsmen. Laboratory investigations should continue to be carried out. The evaluation that took place assessing the effect of loads on human performance, particularly in the case of the sit-skiers, was able to deliver results that can be of use to other WC bound sportsmen, as well as for people who spend many hours a day in the seated position (subject to postural modifications) and people that for some reason must suddenly stay seated for many hours (subject to circulatory trauma).

This experiment as a whole supplied a significant performance evaluation in relation to the sport under analysis. Previous performance diagnostic tests have been conducted that are similar to those in this study, but never before with the disabled. The implementation of these tests are possible without requiring major effort and the collection of laboratory based data regarding alpine skiers could prove useful and reliable for making direct comparisons with performances in actual ski-slope conditions. Among the conceivable future possibilities of this project is the development of a wheelchair that can easily enable posture changes for the performance of specific rehabilitative exercises. Even more importantly is the possibility of using the aerodynamic characteristics encountered as a means for improving the safety of the disabled skiers, whether seated or standing.

The study carried out in the exercise physiology laboratory and in the wind tunnel, simulating the ski run conditions with seated and standing skiers, has produced the possibility of verifying the effect of loads applied to the athletes, whilst also confirming the optimal performance position of each athlete for minimizing the wind resistance, something that can make a great difference to racing results. The implementation and application of the results encountered by this investigation are appropriate and suitable for use in both situations of competing on the ski slopes in racing season, as well as for training purposes out of season.

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## VI. APPENDIX

## Appendix A - Informed Consent

SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN
EINVERSTÄNDNISERKLÄRUNG

DEUTSCHER SPORTBUND

**Einverständniserklärung**

Ich erteile mein Einverständnis zur sportärztlichen Untersuchung, zur Speicherung der erhobenen Daten im Bundesinstitut für Sportwissenschaften und zur Nutzung zu wissenschaftlichen Zwecken. Bei der Nutzung zu wissenschaftlichen Zwecken sind meine Daten so zu verändern, dass kein Bezug zwischen ihnen und meiner Person hergestellt werden kann. Meine personenbezogenen Daten sind für alle Benutzerkreise zu sperren, außer für die ärztlichen Mitarbeiter der Untersuchungszentren, für den von mir im Untersuchungsbogen genannten Heim- und Bundestrainer und für die wissenschaftlichen Mitarbeiter des BL des Deutschen Sportbundes und des BISp. Die Weitergabe meiner personenbezogenen Daten durch diesem Benutzerkreis bedarf meiner schriftlichen Genehmigung.

SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN
EINVERSTÄNDNISERKLÄRUNG

DEUTSCHER SPORTBUND

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EINVERSTÄNDNISERKLÄRUNG

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SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN
EINVERSTÄNDNISERKLÄRUNG

DEUTSCHER SPORTBUND

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SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN
EINVERSTÄNDNISERKLÄRUNG

DEUTSCHER SPORTBUND

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Martin Brakenthaler

**Einverständniserklärung**

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**Appendix B – Clinical Examination - Questionnaire**

DEUTSCHER OLYMPISCHER SPORTBUND

**Einverständniserklärung**

Ich erteile mein Einverständnis zur sportärztlichen Untersuchung, zur Speicherung der erhobenen Daten beim Deutschen Olympischen Sportbund und zur Nutzung zu wissenschaftlichen Zwecken. Bei der Nutzung zu wissenschaftlichen Zwecken sind meine Daten so zu verändern, dass kein Bezug zwischen ihnen und meiner Person hergestellt werden kann. Meine personenbezogenen Daten sind für alle Benutzerkreise zu sperren, außer für die ärztlichen Mitarbeiter/innen der Untersuchungszentren, für die/den von mir im Untersuchungsbogen genannten Heim- und Bundestrainer/in und für die Mitarbeiter/innen mit dem Aufgabengebiet Sportmedizin des Ressorts L1 im Geschäftsbereich Leistungssport des Deutschen Olympischen Sportbundes. Die Weitergabe meiner personenbezogenen Daten durch diesen Benutzerkreis bedarf meiner schriftlichen Einwilligung.

Ich entbinde die untersuchenden Ärzte/innen im Falle begründeter Verdachtsmomente zu möglichen Dopingvergehen von der Schweigepflicht gegenüber dem/der Leiter/in des Untersuchungszentrums und dem/der Anti-Doping-Beauftragten des zuständigen Fachverbandes.

| | |
|---|---|
| C1 | 13.06.1984 |
| Name, Vorname des/der Athleten/in | Geburtsdatum |
| | |
| Datum, Ort | Unterschrift |

# SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN
# GESUNDHEITSBEURTEILUNG

Deutscher Olympischer SportBund

| | | | |
|---|---|---|---|
| Untersuchender Arzt | Dr. med. U.Hillmer-Vogel | Ort der Untersuchung | Sportmedizin, Uni-Göttingen |
| Einverständniserklärung Unterschrift des Athleten | | Untersuchungsdatum | 13.08.2011 |

## A PERSÖNLICHE DATEN

| | | | |
|---|---|---|---|
| Name, Vorname | C1 | Geburtsdatum | 13.06.1984 |
| Straße | | Heimtrainer | |
| PLZ, Ort | | Bundestrainer | Justus Wolf |
| Hauptsportart | Ski alpin | Verbandsarzt | Dr. med. H. Stinus |
| Hauptdisziplin | Ski alpin | | |

## B TRAININGSINHALT (DER LETZTEN TRAININGSEINHEIT)

| | | |
|---|---|---|
| Handbike (Rolle) 18 km | Anzahl der Trainingsjahre in Hauptsportart | 7 |
| 1:30 Std. (10.08.2011) | Trainingseinheiten pro Woche | 6 |
| ) | Trainingsstunden pro Woche | 10 |

## C ALLGEMEINBEFUND (AUFFÄLLIGKEITEN)

Gynäkologische Befragung/Beratung durchgeführt ☐

| | | | |
|---|---|---|---|
| Körpergröße (cm) | 163 | Körperfettanteil (Prozent) | |
| Körpergewicht (kg) | 59,5 | Methode der Köperfettbestimmung | |

| | | | | | |
|---|---|---|---|---|---|
| Sinnesorgane | nein ☒ | ja ☐ | Herz/Kreislauf | nein ☒ | ja ☐ |
| Nasen-/Rachenraum | nein ☒ | ja ☐ | Lunge | nein ☒ | ja ☐ |
| Halsregion | nein ☒ | ja ☐ | Abdominalorgane | nein ☒ | ja ☐ |
| Lymphknoten | nein ☒ | ja ☐ | Gefäßsystem | nein ☒ | ja ☐ |
| Zähne | nein ☒ | ja ☐ | Nervensystem | nein ☐ | ja ☒ |
| Bemerkungen bei Auffälligkeiten | bekannte Paraplegie | | Haut | nein ☒ | ja ☐ |

## D KARDIOVASKULÄRE GESUNDHEITSBEURTEILUNG

| | | | | | |
|---|---|---|---|---|---|
| Ergometrie | Rollstuhlergometrie a.d. Laufband | | | | |
| Ruhe-EKG auffällig | nein ☒ | ja ☐ | | | |
| Belastungs-EKG auffällig | nein ☒ | ja ☐ | | | |
| HV durch Rö/Echo (ml) | | HV/kg KG (ml/kg) | | | |
| Ruhe RR syst./diast. (mmHg) | 120/80 | | | | |
| Maximale Belastungsstufe Watt/kg | 1,68 | m/s | 2 | HF/min | 194 |
| RR syst./diast. Bei Belastung (mmHg) | 185/80 | bei Watt | 3min.n.B. | m/s | |

## E LABORSTATUS

| | | | |
|---|---|---|---|
| BKS Wert1 (mm) | 2 | BKS Wert2 (mm) | |
| HKT (%) | 49,6 | Hb (g/dl) | 14,9 |
| Ery ($10^6$/µl) | 4,89 T/l | Leuko ($10^3$/µl) | 6,1 G/l |
| Blutzucker (mmol/l) | 62 mg/dl | Harnstoff (mmol/l) | 37 mg/dl |
| Kreatinin (µmol/l) | 0,5 mg/dl | Harnsäure (µmol/l) | 4,4 |
| Gesamtcholesterin (mmol/l) | 108 | HDL Cholesterin (mmol/l) | 59 mg/dl |
| Gamma GT (U/l) | 19 | SGPT (U/l) | 19 mg/dl |
| Kalium (mmol/l) | 5,5 | Magnesium (mmol/l) | 2,15 mg/dl |
| Eisen (µmol/l) | 106 µg/dl | Ferritin (ng/ml) | 110 µg/l |
| Urin auffällig | nein ☒ ja ☐ | Tryglyceride (mmol/l) | 78 |
| Gesamt-CK (U/l) | 28 | Blutentnahme | nein ☐ ja ☒ |

SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN

LEISTUNGSDIAGNOSTIK

Deutscher Olympischer SportBund

Name, Vorname C1
Hauptsportart, Kader Ski alpin
Hauptdisziplin
Geburtsdatum 13.06.1984
Untersuchungsdatum 13.08.2011

**F ERGOMETRIE / LEISTUNGSDIAGNOSTIK**

Testverfahren Rollstuhlergometrie a.d. LB   Einheit   Siehe Anlage!
Stufendauer (min) 3

| Belastungsstufe | HF ($min^{-1}$) | Lactat (mmol/l) | $VO_2$/kg (ml/min) | Andere Messgrößen |
|---|---|---|---|---|
| | | | | |
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| | | | | |
| | | | | |

| Erholung | HF ($min^{-1}$) | Lactat (mmol/l) | RR (mmHg) |
|---|---|---|---|
| 1. min | | | |
| 3. min | | | |
| 5. min | | | |
| 10. min | | | |

Schwelle bei 4 mmol/l Lactat
$VO_2$/kg (ml/min) ______ Watt/kg ______ m/s ______ HF/min ______
Individuelle Schwelle bei ______ mmol/l Lactat
$VO_2$/kg (ml/min) ______ Watt/kg ______ m/s ______ HF/min ______

**G SPEZIFISCHE TESTVERFAHREN**

Testverfahren ______ Einheit ______
aerober Test ☐ anaerober ☐ Feldtest ☐

| Belastungsstufe | HF ($min^{-1}$) | Lactat | $VO_2$ | Andere Messgrößen |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
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SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN

BEURTEILUNG

| | | | |
|---|---|---|---|
| Name, Vorname | C1 | Geburtsdatum | 13.06.1984 |
| Hauptsportart, Kader | Ski alpin | Untersuchungsdatum | 13.08.2011 |

| | | |
|---|---|---|
| Volltauglich | nein ☐ | ja ☒ |
| Arztüberweisung | nein ☒ | ja ☐ |

**Anamnese, Zusammenfassung der Befunde und sportmedizinische Beurteilung, einschließlich Hinweise für den Trainer und den Athleten:**

Siehe Anlage:
Kurzbericht zur LD am 13.08.2011 von Prof. Dr.Dr. A. Niklas.

Verantwortlicher Arzt Prof. Dr. med. et Dr. rer. nat. A. Niklas

Unterschrift der verantwortlichen Arztes ______________________

# SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN
# KLEINE ORTHOPÄDIE (BEWEGUNGSAPPARAT)

Deutscher Olympischer SportBund

| | | | |
|---|---|---|---|
| Name, Vorname | C1 | Geburtsdatum | 13.06.1984 |
| Hauptsportart, Kader | Ski Alpin | Untersuchungsdatum | 13.08.2011 |

| | **Befund: ohne** | **mit** | **Bemerkung/Befund** |
|---|---|---|---|
| Beckenstellung | ☒ | ☐ | höher links ☐ rechts ☐<br>_____ cm Bem.: |
| Wirbelsäule (Haltung, Krümmungsverhältnisse) | ☐ | ☒ | leichte Skoliotische Fehlstellung ohne Progredienz |
| Wirbelsäulenbeweglichkeit | ☐ | ☒ | mit Befund ☐ HWS ☐ BWS ☒ LWS<br>Querschnittslähmung in Höhe Th 12 n. Unfall 1993 |
| Hüftgelenk | ☒ | ☐ | |
| Kniegelenk | ☐ | ☒ | Streckdefizit 20° bds. |
| Sprunggelenk/Füße | ☒ | ☐ | |
| Untere Gliedmaßen (sonstiges) | ☒ | ☐ | |
| Schulter | ☒ | ☐ | |
| Ellenbogen/Unterarm | ☒ | ☐ | |
| Hand/Finger | ☒ | ☐ | |
| Obere Gliedmaßen (sonstiges) | ☒ | ☐ | |
| Hypermobilität/Bänderschwäche | ☒ | ☐ | |
| Muskelstatus | ☐ | ☒ | sehr guter Restmuskelzustand |

Beschwerden: orthopädisch keine Beschwerden

Operationen: Spondylodese Th11- L1 1993

Präventive oder therapeutische Maßnahmen: weiter so

Sporttauglichkeit: ja

Vorstellung beim Orthopäden des zuständigen OSP Ja ☐ Nein ☒

Untersuchender Arzt: Dr. Hartmut Stinus

Unterschrift des Arztes: __________

SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN

ORTHOPÄDIE

Deutscher Olympischer SportBund

Name, Vorname C1

Hauptsportart, Kader Ski alpin

Geburtsdatum 13.06.1984

Untersuchungsdatum 13.08.2011

**H Allgemein**

| | o.p.B. | B.o.Th. | Th. |
|---|---|---|---|
| Hockstellung | ☐ | ☐ | ☐ |
| Zehenstand | ☐ | ☐ | ☐ |
| Fersenstand | ☐ | ☐ | ☐ |

Beckenstand gerade ☐ li.___cm tiefer re.___cm tiefer

Rückenform unauffällig ☒ hohl ☐ rund ☐ flach ☐

Skoliose keine ☐ thorakal ☒ lumbal ☒

Beinachse gerade ☐ X-Beine ☐ O-Beine ☐

Fußform Knick ☐ Senk ☐ Spreiz ☐ Hohl ☐

Anmerkungen Querschnittslähmung TH 12

**I HWS**

Inklination / Reklination [45/0/45] 45 / 0 / 45

Li.-Re.-Rotation [80/0/80] 80 / 0 / 80

Li.Re.-Seitneigung [45/0/45] 45 / 0 / 45

Anmerkungen

**J BWS**

Anmerkungen o.B.

**K LWS**

Inklination / Reklination [90/0/40] 90 / 0 / 40

| | o.p.B. | B.o.Th. | Th. |
|---|---|---|---|
| Lasèque | ☐ | ☐ | ☐ |

Anmerkungen fixierte Stellung

| | | | |
|---|---|---|---|
| Neurologie: Sensomotorische Defizite | ☐ | ☐ | ☐ |

**L Schulter**

Anteversion / Retroversion [180/0/40] li. 180 / 0 / 40 re. 180 / 0 / 40

Abduktion / Adduktion [180/0/40] li. 180 / 0 / 40 re. 180 / 0 / 40

Außen- / Innenrotation [50/0/90] li. 50 / 0 / 90 re. 50 / 0 / 90

| | o.p.B. | B.o.Th. | Th. |
|---|---|---|---|
| Gelenkstabilität | ☒ | ☐ | ☐ |
| Subacromialraum | ☒ | ☐ | ☐ |
| AC-Gelenk | ☒ | ☐ | ☐ |
| Sehnen (Biceps, Supraspinatus) | ☒ | ☐ | ☐ |

Anmerkungen

**M Ellbogen**

Extension / Flexion [5/0/150] li. 5 / 0 / 150 re. 5 / 0 / 150

| | o.p.B. | B.o.Th. | Th. |
|---|---|---|---|
| Epicondylus | ☒ | ☐ | ☐ |
| Seitenbänder | ☒ | ☐ | ☐ |

Anmerkungen

**N Handgelenke und Hände**

Anmerkungen

**O Hüfte**

Extension / Flexion [0/0/150] li. 0 / 0 / 150 re. 0 / 0 / 150

Abduktion / Adduktion [40/0/40] li. 40 / 0 / 40 re. 40 / 0 / 40

Außen- / Innenrotation [40/0/30] li. 40 / 0 / 30 re. 40 / 0 / 30

Anmerkungen Querschnittslähmung TH 5, keine wesentliche Kontraktur

**P Knie**

Extension / Flexion [5/0/150] li. 5 / 0 / 150 re. 5 / 0 / 150

| | o.p.B. | B.o.Th. | Th. |
|---|---|---|---|
| Menisken | ☐ | ☐ | ☐ |
| Kreuzbänder | ☐ | ☐ | ☐ |
| Seitenbänder | ☐ | ☐ | ☐ |
| Femoropatellares Gleitlager | ☐ | ☐ | ☐ |
| Sehnen (Patella, Quadriceps) | ☐ | ☐ | ☐ |

Anmerkungen Extension /Flexion: li: 0/20 ; re.:0/20

**Q Sprunggelenke**

Dorsalextension/Plantarflexion [30/0/50] li. 30 / 0 / 50 re. 30 / 0 / 50

| | o.p.B. | B.o.Th. | Th. |
|---|---|---|---|
| Außenbänder | ☐ | ☐ | ☐ |

Anmerkungen nicht untersucht wg. Querschnittslähmung

**R Füße**

| | o.p.B. | B.o.Th. | Th. |
|---|---|---|---|
| Achillessehne | ☒ | ☐ | ☐ |
| Plantarfascie | ☒ | ☐ | ☐ |

Anmerkungen

Schlüssel: o.p.B.= ohne pathologischen Befund; B.o.Th. = Befund ohne Therapiebedarf; Th. = Therapiebedarf

SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN

ORTHOPÄDIE

Deutscher Olympischer SportBund

| | | | |
|---|---|---|---|
| Name, Vorname | C1 | Geburtsdatum | 13.06.1984 |
| Hauptsportart, Kader | Ski alpin | Untersuchungsdatum | 13.08.2011 |

**R ORTHOPÄDISCHE RÖNTGENAUFNAHMEN**

| | | | | |
|---|---|---|---|---|
| | | | | |

Schlüssel: Eb. = Ebene(n)
wEb. = weitere Ebenen

| | | |
|---|---|---|
| 5010 = Finger od. Zehen 2 Eb. | 5030 = Ellenbogengelenk 2 Eb. | 5100 = HWS 2 Eb. |
| 5011 = Finger od. Zehen wEb. | 5030 = Oberschenkel 2 Eb. | 5101 = HWS wEb. |
| 5020 = Handgelenk 2 Eb. | 5030 = Unterschenkel 2 Eb. | 5105 = BWS od. LWS je Teil 2 Eb. |
| 5020 = Mittelhand 2 Eb. | 5030 = Kniegelenk 2 Eb. | 5106 = BWS od. LWS je Teil wEb. |
| 5020 = alle Finger einer Hand 2 Eb. | 5030 = Hand od. Fuß 2 Eb. | 5110 = Ganzaufnahme Wirbelsäule od. einer Extremität |
| 5020 = Sprunggelnk 2 Eb. | 5030 = Gelenke Schulter 2 Eb. | |
| 5020 = Fußwurzel u. od. Mittelfuß 2 Eb. | 5030 = Schlüsselbein 2 Eb. | 5111 = Ganzaufnahme Wirbelsäule od. einer Extremität wEb. |
| 5020 = Kniescheibe 2 Eb. | 5030 = Beckenteilaufnahme 2 Eb. | |
| 5021 = 5020 wEb. | 5030 = Kreuzbein od. Hüftgelenk 2 Eb. | 5120 = Rippen einer Thoraxhälfte 1 Eb. |
| 5030 = Oberarm 2 Eb. | 5031 = 5030 wEb. | 5120 = Schulterblatt od. Brustbein 1 Eb. |
| 5030 = Unterarm 2 Eb. | 5040 = Beckenübersicht | 5121 = 5120 wEb. |

**Anlagen**

**Hinweise für Athlet, Trainer und Verbandsarzt / auffällige Befunde, präventive oder therapeutische Maßnahmen, Prognose, Sporttauglichkeit:**

**Gut trainierter Athlet ohne orthopädische Probleme.**

Untersuchender Facharzt für Orthopädie Dr. med. H. Stinus (Mannschaftsarzt)

SPORTÄRZTLICHER UNTERSUCHUNGSBOGEN

ZUSATZUNTERSUCHUNGEN

| | | | |
|---|---|---|---|
| Name, Vorname | C1 | Geburtsdatum | 13.06.1984 |
| Hauptsportart, Kader | Ski alpin | Untersuchungsdatum | 01.11.2010 |

**ZUSATZUNTERSUCHUNGEN**

| **Untersuchung** | **gemacht** |
|---|---|
| Ultraschallbeurteilung | ☐ |
| Ultraschallbeurteilung (weitere Untersuchung) (Anzahl 1-3) | ______ |
| Sonographie der Extremitätenarterien bzw. –venen | ☐ |
| Sonographie der hirnversorgenden Arterien | ☐ |
| Lungenfunktion – Spirometrie | ☐ |
| Lungenfunktion – Blutgase | ☐ |
| Muskelfunktionsdiagnostik (u.a. Neuromuskuläre Erregbarkeit) | ☐ |
| Farbdopplerechokardiographie | ☒ |
| C-reaktives Protein | ☐ |
| Antistreptolysin – Titer | ☐ |
| Immunglobuline (IgA) | ☐ |
| Immunglobuline (IgG) | ☐ |
| Immunglobuline (IgM) | ☐ |
| Sehtest | ☐ |
| Sondermaßnahme | ☐ |
| Blutbild | ☒ |
| Zink | ☐ |
| Broncholysetestwerte (Anzahl 1-5) | ______ |

## Appendix C - Spiroergometry - Checklist

### Ergometry Laboratory

| | |
|---|---|
| Room – light, ventilation, access | |
| Environment (sport pictures/ panels or landscape) | |
| **Temperature** (Variation between 20º and 24º C) RU 60% - Termometer, Hygrometer | |
| Personal:<br><br>Dr. Med. Niklas<br>Dr. Med. Hilmer-Vogel<br>Dr. Med. Stinus<br>Dr. Fisio. Wuttke<br>Dr. Hottowitz<br>MTA. Asendorf<br>MSc. Vinagre | |
| Test Equipment (ECG measurement) | |
| Material and Emergency medicine | |
| ***Spiroergometer*** (See the Calibration procedure at the end of this checklist) | |
| • Materials | |
| • Medicine | |

### Mainly Routines of the Spiroergometry

| **a. Baseline** - Pre-test | | **b. Test** | |
|---|---|---|---|
| Recomendation to the Subject | | Subject Adaptation to the method | |
| Identification (secretary) | | Continuous observation of cardioscope | |
| Anamnese (doctor or Phys.Ed. Teacher) | | HR and BP register | |
| Skin preparation and application of electrodes | | Test Interruption (maximal exertion) | |
| Basal and Hiperventilated Register | | Subject Test Interruption | |
| Initial Cardiac Examination | | | |
| Protocol choice | | | |

| **c. Recovery -** Pos-Test Routine (2 min.; cool down) | |
|---|---|
| • Gradual stop | |
| • Signs and Symtoms | |
| • HR and BP register (imediatelly after the test, 3’, 5’) | |
| • Cardiopulmonary Auscultation | |
| • Subject delivery | |

## Test Routine

### I. Part - Baseline

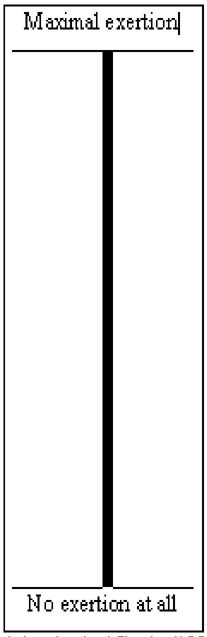
| | |
|---|---|
| **1.** Subject Reception | |
| **2.** Pre-Test Questionnaire/ Anamnesis/ Informed Consentiment (Consent form) | |
| **3.** Subject Preparation | |
| **(a)** Rest Parameters Verification (**HR, BP, ECG**). | |
| **(b)** Preparing skin for exercise testing | |
| **(c)** Lactate Verification | |
| **4.** Objective explanation to the Subject the procedure of the test; present the laboratory and equipments. | |

### II. Part - Cardiopulmonary Exercise Test – Test/ Recovery

| | |
|---|---|
| **Immediately before the Test** | |
| **1.** Make sure that the questionnaire of the Subject has been adequately filled. | |
| **2.** Perform cardiopulmonary physical examination (**noting the findings**) and, unless they have been made very recently (days), spirometry and 12-lead ECG. | |
| **3.** Familiarize the evaluated Subject with the ergometer and mouthpiece/ mask: explain in detail the sequence of events and precautions to be observed, mainly: | |
| **(a)** Need to contact non-verbal communication: establishing communication via sign language. | |
| **(b)** Emphasize the possibility of interrupting the test by the Subject at any time. | |
| **(c)** Carefully explain the symptoms scale to be used: "establish" the maximum value as the biggest breathlessness/ leg fatigue/ general tiredness that the evaluated Subject ever felt. | |
| **4.** Place ECG electrodes respecting derivational schemes. | |
| **5.** Set the protocol to be followed, including the time for rest, zero charge and recovery. | |
| **6. During the Test:** | |
| **(a)** Keep the patient safe and constant verbally stimulated; target them to the doctor. | |
| **(b)** Closely monitor cardiac electrical activity on the monitor. | |
| **(c)** Get Electrocardiographic, systemic blood pressure periodically. | |
| **(d)** Inquire, minute-by-minute, about the symptoms according to one of the available scales (Borg Scale), noting the values in a standard form. | |
| **(e)** Observe carefully the absence of air leak from the nozzle or the rest of the system; make sure that the registered values are physiologically coherent. | |
| **7.** Strictly obey the criteria for interrupting the test described below. | |
| **8.** After removal of the mouthpiece/ mask, inquire about the nature and intensity of limiting symptoms, record them in standard form. | |
| **9.** Make sure the normalization of the ECG (documenting it) and systemic blood pressure before the release of the Subject. | |

| | |
|---|---|
| 0 | No exertion at all |
| 0,5 | Extremely Light |
| 1 | Very Light |
| 2 | Light |
| 3 | Moderate |
| 4 | Somewhat Hard |
| 5 | Hard |
| 6 | |
| 7 | Very Hard |
| 8 | |
| 9 | |
| 10 | Extremely Hard |
| • | Maximal Exertion |

The Borg 0-10 perceived exertion scale (modified).



Visual Analogical Scale (100mm).

The categoric Borg Scale (modified to 10 points) & Visual analogical, to quantify symptoms related to effort.

| | |
|---|---|
| 6 | No exertion at all |
| 7 | |
| 8 | Extremely light |
| 9 | Very light |
| 10 | |
| 11 | Light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Extremely hard |
| 20 | Maximal exertion |

The Borg 6-20 perceived exertion scale, 1985.

| | | |
|---|---|---|
| 6 | Überhaupt nicht anstrengend | |
| 7 | Extrem leicht | |
| 8 | | |
| 9 | Sehr leicht | |
| 10 | | |
| 11 | Leicht | |
| 12 | | |
| 13 | Etwas anstrengend | |
| 14 | | |
| 15 | Anstrengend | schwer |
| 16 | | |
| 17 | Sehr anstrengend | |
| 18 | | |
| 19 | Extrem anstrengend | |
| 20 | Maximale Anstrengung | |

(RPE, „ratings of perceived exertion"). Anleitungen zum Gebrauch in verschiedenen Sprachen mit einer autorisierten Fassung sind in Vorbereitung, (siehe auch Editorial), Copyright Gunnar Borg, mit freundlicher Genehmigung.

**Abbildung: Die „Borg-RPE-Skala" zur Schätzung des Anstrengungsempfindens**

## III. Part - Indications for Stopping an Exercise Test

| | |
|---|---|
| 1. | Progressive angina (stop at 3+ level or earlier on a scale of 1+ to 4+) |
| 2. | Ventricular tachycardia |
| 3. | Any significant drop (20 mmHg) of systolic blood pressure |
| 4. | Lightheadedness, confusion, ataxia, pallor and cold sweats, cyanosis, nausea, or signs of severe peripheral circulatory insufficiency |
| 5. | >2mm horizontal or downsloping ST depression or elevation (in the absence of other indicators of ischemia) |
| 6. | Onset of second- or third-degree A-V block |
| 7. | Increasing ventricular ectopy, multiform PVCs, or R on PVCs (premature ventricular contractions) |
| 8. | Excessive rise in blood pressure: systolic pressure > 250 mmHg; diastolic pressure > 120 mmHg |
| 9. | Chronotropic impairment |
| 10. | Sustained supraventricular tachycardia |
| 11. | Exercise-induced left bundle branch block |
| 12. | Subject asks to stop |
| 13. | Failure of the monitoring system |

Reprinted from American College of Sports Medicine, 2003.

***Spiroergometrie* Test Equipments – <u>Calibrate at least 30 min. before the test.</u>**

**Before starting the measurement:**

- Early turn the device in order to heating the analyzers.
- Drying tube filled with a new lime.

**Calibration:**

- Set pump power of the analyzers to 60 l/ h
- Gas of high accuracy with 40-60 l/ h for about 30sec. let in the Analyzer suck modus.
- Calibration of using the potentiometer.
- Expression of values.
- Calibration as above, but from ambient air (two-point calibration).

# Appendix D - Anamnesis

## Untersuchungsbogen - Ergometrie

### Persönliche Daten:

Name: ____________________

Vorname: ____________________

Geburtsname: ____________________

Geb.Datum: ____________ männlich / weiblich ____________

Beruf: ____________________

Straße: ____________________

Ort: ____________________

### Sportanamnese (letztes Halbjahr!):

| Welche Sportarten: Sportart: | Train. häufigk./ Woche | Train. std./ Woche | Ursache u. Dauer von Train.pausen? |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

Körperl.Aktivitäten im Beruf /
auf dem Weg zur Arbeit / in der Freizeit: ____________________

Bemerkungen: ____________________

____________________

### Eigenanamnese:

### Vegetative Anamnese:

Schlafstörungen: ____________ Appetitstörungen: ____________

Verdauungsstörungen: ____________ Kopfschmerzen: ____________

Gewichtsveränderung von mind. 2kg in den letzten 4 Wochen: ____________

Bemerkungen/Besonderheiten: ____________________

**Gesamte** Vorgeschichte: ja / nein

**Ergänzungen** seit letzter Untersuchung vom: ______________________________

Krankenhausbehandlungen, Operationen, Verletzungen oder Unfälle ?

______________________________

______________________________

Haben oder hatten Sie Beschwerden oder Erkrankungen folgender Organe oder Körperfunktionen

Herz-Kreislauf-System : ______________________________

Atmungsorgane : ______________________________

Verdauungsorgane : ______________________________

Nieren, Harnwege, Geschlechtsorgane : ______________________________

Haut, Knochen, Gelenke : ______________________________

Muskelerkrankungen : ______________________________

Stoffwechsel : Schilddrüse, Bauchspeicheldrüse, Nebenniere, Fettstoffwechselstörungen :

______________________________

Nervensystem : ______________________________

Psyche : ______________________________

Nase, Nasennebenhöhlen : ______________________________

Ohren : ______________________________

Augen : ______________________________

bei Frauen : Schwangerschaft

Schwangerschaftsverhütung : ______________________________

Hatten Sie **fieberhafte Erkrankungen** in den letzten Wochen (was / wann ?) : ___________

______________________________

Allergische Erkrankungen / Allergien :

______________________________

**Welche Medikamente nehmen Sie** ? ______________________________

______________________________

Hatten oder haben Sie sonstige **Krankheiten, Fehler oder Beschwerden**, nach denen nicht ausdrücklich gefragt wurde (was / wann) ? ______________________________

______________________________

## Appendix E – Protocol of Evaluation

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | **Auswertungsprotokoll:** | | | | |
| | | | | | |
| | | Rollstuhlergometrie -Vita max.- | | | |
| | | | Ski-Alpin | | |
| | | | | | |
| | **Name:** | | | **Datum:** | |
| | | | | | |
| | | | | | |
| | **Stufen:** | **Lactat** | **HR** | **RR** | **RPE** |
| | | **[mmol/l]** | **[$min^{-1}$]** | **[mmHg]** | |
| | Vorstart | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
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| | | | | | |

Uni-Göttingen
-Sportmedizin-

## Appendix F – Recommended Pilates Exercises to the sit skiers

Ersten 3 Übungen

- auf dem Rollstuhl adaptieren können.

### *Spine Twist* (Drehen der Wirbelsäule)

- Setzen Sie sich aufrecht auf den Boden und halten die Beine geschlossen. Die Füße sind angewinkelt.
- Strecken Sie die Arme mit nach unten gekehrten Handflächen zur Seite aus.
- Einatmen.
- Beginnen Sie die Drehbewegung vom Kopf aus und lassen Sie die Wirbelsäule folgen.
- Ausatmen. Halten Sie am Ende des Bewegungsspielraums kurz innen und drehen Sie sich wieder in die Ausgangsposition zurück.
- Wiederholen die Drehung in die andere Richtung. Wiederholen Sie die Übung 3 Mal jeder Seite.

Trainierte Muskeln: Bauchmusklen, Rückenstrecker und WS mobilität.

Beispiel Foto von erste Übung.

### *Spine Twist* mit extension und flexion des Ellenbogen

- Setzen Sie sich aufrecht auf den Boden und halten die Beine geschlossen. Die Füße sind angewinkelt.
- Verschränken die Arme vorne. Einatmen.
- Beide Arme etwas öffnet und dann beginnen Sie den Oberkörper aus der Taille heraus zu drehen.
- Die Arme werden dabei mitgeführt, der in Drehrichtung stehender Arm öffnet sicht und verstärkt die Drehnung - dieser erfolgt nur aus der Taille.
- Ausatmen. Halten Sie am Ende des Bewegungsspielraums kurz innen und drehen Sie sich wieder in die Ausgangsposition zurück.
- Wiederholen die Drehung in die andere Richtung. Wiederholen Sie die Übung 3 Mal jeder Seite.

### *Spine Twist* mit gebeugte Ellbogen

- Setzen Sie sich aufrecht auf den Boden und halten die Beine geschlossen. Die Füße sind angewinkelt.
- Verschränken die Arme vorne. Einatmen.
- Beginnen Sie die Drehbewegung vom Kopf aus und lassen Sie die Wirbelsäule folgen.
- Ausatmen. Halten Sie am Ende des Bewegungsspielraums kurz innen und drehen Sie sich wieder in die Ausgangsposition zurück.

❖ Wiederholen die Drehung in die andere Richtung. Wiederholen Sie die Übung 3 Mal jeder Seite

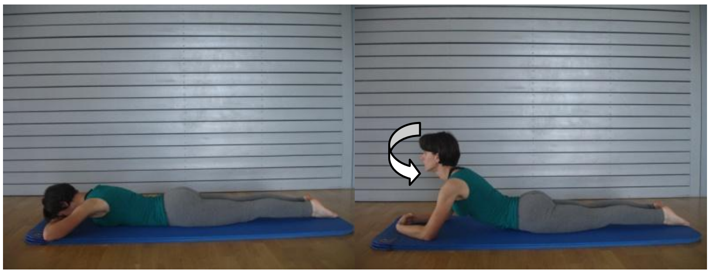
Letzen 3 Übungen

- auf der Matte adaptieren müssen

### ***Neck Roll***

❖ Liegen Sie im Bauchlage.
❖ Beide Beine gestreckt mit gestreckten Füßen.
❖ Legen Sie die Handflächen direkt unter den Kopf auf der Matte.
❖ Heben Sie den Oberkörper nach oben. Einatmen und Powerhouse aktivieren dann ziehen Sie den nabel fest zur WS und drehen Sie den Kopf nach rechts. Ausatmen und den kopf nach vorne zurück. Nun den Kopf  nach links drehen.
❖ Wiederholen die Drehung in die andere Richtung. Wiederholen Sie die Übung 4 Mal jeder Seite.

Trainierte Muskeln: Rückenstrecker, Bauchmuskulatur



### ***Double Leg Kick*** **(adaptiert Übung - ohne Bein Bewegung)**

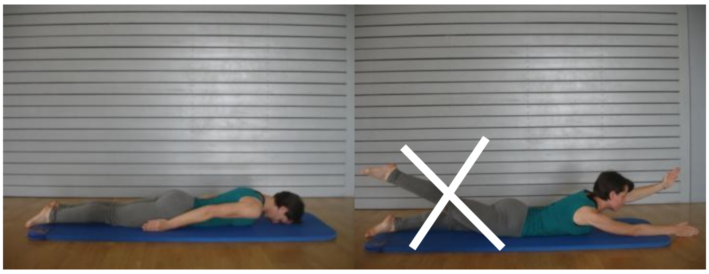
❖ Legen Sie im Bauchlage mit gedrehtem Kopf nach rechts.
❖ Schließen Sie die Hände hinter dem Rücken und legen Sie sie so hoch wie möglich auf den Rücken.
❖ Spreizen Sie die Ellenbogen und legen Sie sie auf der Matte.
❖ Einatmen. Strecken Sie dann die verschränkten Hände nach hinten, über den Rücken hinweg.
❖ Ausatmen, zurück zur ausgangsposition.
❖ Drehen jetzt den Kopf nach links und wiederholen die Übung.
❖ Diese Übung 3 Mal jeder Seite machen werden.

Trainierte Muskeln: Lendenwirbelsäule, Gesäßmuskeln, Rhombusmuskeln, mittlerer Trapezius, Brustmuskeln, Infraspinatus und Teres minor.

**_Swimming_ (adaptiert Übung - ohne Bein Bewegung)**

- Legen Sie sich mit anch vorne gestreckten Armen und nach unten gekehrten Handflächen auf den Boden. Die Beine sind auch gestreckt.
- Heben Sie den Brustkorb und die Arme von der Matte. Bleiben Sie dabei lang gestreckt.
- Einatmen. Heben Sie mit kontrollierten, aber raschen Bewegungen (wie Ruderschläge, aber ohne großes Geplantsche) abwechseln Arme (Austamen), immer über Kreuz und im gleiche Tempo.
- Wiederholen Sie die Übung 5 Mal jede Arm.

Trainierte Muskeln: vordere Brustmuskeln und Rückenstrecker.



- Diese Reihe Übungen wurde basierte auf Pilates-Methode des körperlichen Trainings. Das Programm des Trainings der Athleten von dieser dreieingefügt mal pro Woche mit Dauer von ungefähr 10 Minuten. Training wurde von Sport Lehrerin Fernanda Buffé organisiert und modifiziert (Die Fotos wurden durch die selben geliefert).

# VII. ANNEX

## Annex 1 - The Central Nervous System

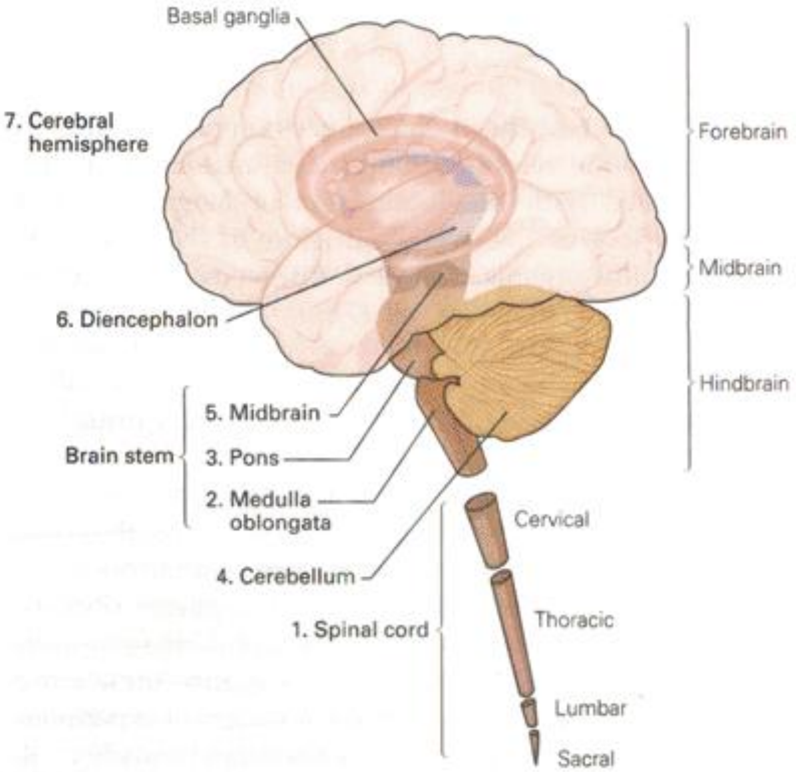



Figure 2: The Central Nervous System. Brain and Spinal Cord (Kandel ER, Shwartz JH. 2006).

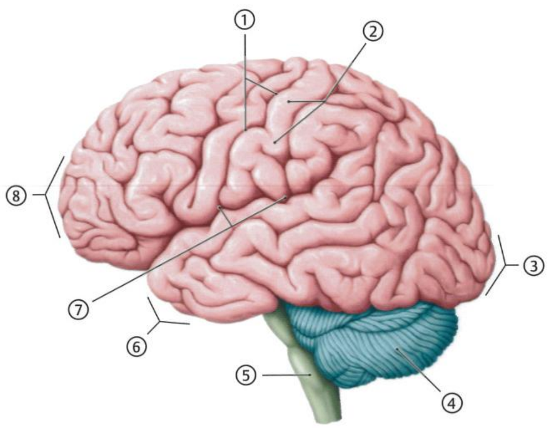



Figure 3: Encephalon. Central sulcus (1), Somatosensory cortex (2), Occiptal Lobe (3), Cerebellum (4), Brainstem (5), Temporal Lobe (6), Lateral Sulcus (7), Frontal Lobe (8). (Schünke M, Schulte E, Schumacher U, Voll M, Wesker K.Prometheus, 2010.)

# Annex 2 - The Spinal Cord

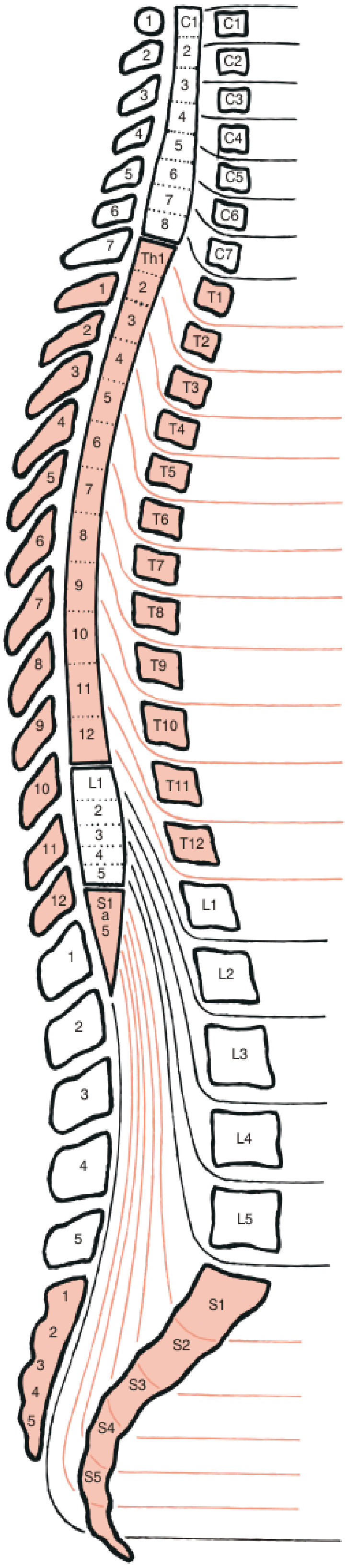
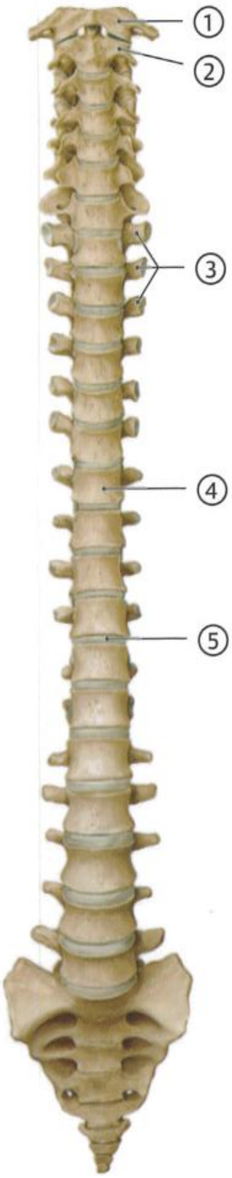



Figure 4: The Spinal Cord. (Education and Prevention Research Centre from the SARAH Network of Rehabilitation Hospitals).

## Annex 3 - Vertebral Column





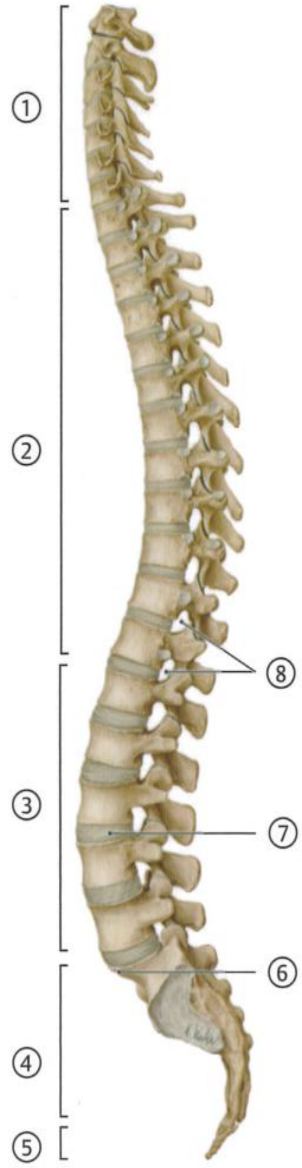



Figure 6: Vertebral Column anterior view. 1. Atlas; 2. Axis; 3. Spinous Process; 4. Vertebral Body; 5. Intervertebral disc.

Figure 7: Vertebral Column posterior view. 7/8. Spinous Process; 6. Vertebral Body.

Figure 8: Vertebral Column lateral view. Regions: 1. Cervical; 2. Thoracic; 3. Lumbar; 4. Sacral; 5. Coccygeal; 6/7/8. Intervertebral disc. (Schünke M, Schulte E, Schumacher U, Voll M, Wesker K.Prometheus, 2010)

**Annex 4 - Characteristics of the Ergoselect 200 Electric Bicycle Ergometer.**

| ergoline | Gebrauchsanweisung<br>Anhang D: Technische Daten | ergoselect<br>100 / 200 |
|---|---|---|

## Anhang D: Technische Daten

ergo select 100 200 Typ P Typ K NiBP

| | |
|---|---|
| Ausführung: | modulares Ergometer-System **ergoselect**<br>Modelle ergoselect 100P / 100K, ergoselect 200P / 200K |
| Betriebsart: | Dauerbetrieb |
| Stromversorgung: | 100 - 240 V / 50 - 60 Hz |
| Leistungsaufnahme: | max. 60 VA |
| Sicherungen: | 2 x 1,25 AT |
| Bremsprinzip: | computergesteuerte Wirbelstrombremse mit Drehmomentmessung, drehzahlunabhängig nach DIN VDE 0750-0238 |
| Belastungsbereich: | 20 . . . 999 Watt, drehzahlunabhängig |
| Drehzahlbereich: | 30 . . . 130 n/min⁻¹ |
| Abweichung der aufgenommenen Leistung: | max. ± 3% zwischen 100 und 999 W<br>max. ± 3 W zwischen 20 und 100 W |
| Belastungsstufen: | 5 W manuell, 5 W oder vielfaches über Programm |
| Interne Programme: | |
| mit **Bedieneinheit Typ P**: | Ergometrie: 5 feste Stufenprogramme (WHO, Hollmann, u.a.)<br>10 Programme frei programmierbar (siehe Tabelle C-1)<br>manuelle Laststeuerung |
| mit **Bedieneinheit Typ K**: | Ergometrie: 5 feste Stufenprogramme (WHO, Hollmann, u.a.)<br>10 Programme frei programmierbar (siehe Tabelle C-1)<br>manuelle Laststeuerung<br>4 Ergometrie-Testprogramme (siehe Tabelle C-3)<br>10 Trainingsprogramme frei programmierbar (siehe Anhang C-3) |
| Zul. Patientengewicht: | 150 kg |
| Sitzhöhenverstellung: | stufenlos für Körpergröße 120 cm bis 210 cm |
| **ergoselect 100**: | manuelle Verstellung der Sitzhöhe |
| **ergoselect 200**: | elektrische Verstellung der Sitzhöhe per Software<br>digitale Anzeige der Sitzhöhe |
| Verstellung des Lenkergriffs: | für Körpergröße 120 cm bis 210 cm |
| **ergoselect 100**: | starre Lenksäule, Lenkerbügel um 360° stufenlos verstellbar |
| **ergoselect 200**: | Höhenverstellung der Lenksäule, Lenkerbügel um 360° stufenlos verstellbar |
| Anzeigen: | LCD-Display sowie LED-Display als zusätzliche Drehzahlanzeige |
| mit **Bedieneinheit Typ P**: | LCD-Display : 68 x 34 mm bzw. 128 x 64 Pixel |
| mit **Bedieneinheit Typ K**: | LCD-Display : 115 x 88 mm bzw. 320 x 240 Pixel |
| Schnittstellen: | **PORT 1**: RS232 mit Fernstart, 9-pol- Sub-D<br>**PORT 2**: RS232, 9-pol- Sub-D, nur für Service-Zwecke<br>**PORT 3**: RS232, 5-pol. DIN-Buchse<br>**ANALOG**: Analogeingang/-ausgang für Solllast, Fernstart<br>Fernstart EKG (Start-Puls für EKG); 1 bis 30 Sek. vor Lastwechsel<br>**SERVICE**: analog Soll-/Istlast, HF, Systole, Diastole, Drehzahl und für Servicezwecke |
| **Bedieneinheit Typ K**: | Polarempfänger integriert |
| Gewicht: | |
| **ergoselect 100**: | ca. 64 kg |
| **ergoselect 200**: | ca. 68 kg |
| Abmessungen (B x L):<br>Höhe: | 460 x 900 mm, Lenkerbreite: ca. 575 mm<br>min: ca. 960 mm; max: ca. 1350 mm |
| Kalibrierung: | softwaremäßig über Tastatur / PC mit 8 kg Eichgewicht |
| Schutz der Kalibrierung: | Code |

Version: 10/05 D - 69 Gebrauchsanweisung **ergoselect 100 / 200**

## Annex 5 - Characteristics of the Spirometer Metamax 3B

# MetaMax® 3B

unattached mobile

The MetaMax® 3B is a stable out- and indoor device for mobile use. The system allows a complete Cardiopulmonary Exercise Testing even outside of a laboratory. Battery operation and bidirectional transmission ensure a particulary wide scope of usage. This means: put it on, switch it on and measure. Various hardware additions and matching software options make it a very flexible tool.

### SCOPE OF DELIVERY

- MetaMax® 3B Base Unit
- Triple V Volume Transducer incl. Windshield
- Face Mask Set dark blue (S, M) incl. Adapter and Headgear
- Polar® HR Transmitter Belt & Elastic Strap
- Telemetry Receiver with Connection Cable
- 2 Internal Batteries with Charger
- Earphone
- MaxSport Jacket Set, incl. 2 Jackets (S, L)
- Gas Sample Line, mobile
- PC Connection Cable
- Cable USB/Serial
- Digital Barometer Airflow
- MetaSoft® Studio Software incl. Exercise Devise Control and Dongle
- Operator Manual
- Carrying Case with Inlay

### ACCESSORIES & OPTIONS

- GPS Kit for MetaMax®
- 12-Channel ECG
- 3-Channel ECG
- Blood Pressure Module Tango+
- External SpO2 Module Ipod® / Xpod®
- Personal-Use Mask incl. Mask Harness
- Calibration Set
- Workload Devices (Treadmill; Bicycle)
- Software Options
- System cart CORTEX mobile PLUS
- Notebook / PC
- Color Printer

### MEASURING METHOD / SENSORS

| | | |
|---|---|---|
| Measuring Method | Breath-by-Breath | |
| Flow / Volume | Type | Turbine digital |
| | Range | 0.05 - 20 L/s |
| | Resolution | 7 mL |
| | Accuracy | ± 2 % |
| $O_2$ | Type | Electro-Chemical Cell |
| | Range | 0 - 100 Vol. % |
| | $T_{90}$ Time | <100 ms |
| | Accuracy | ± 0.1 Vol. % |
| $CO_2$ | Type | ND Infrared |
| | Range | 0 - 13 % Vol. |
| | $T_{90}$ Time | <100 ms |
| | Accuracy | ± 0.1 Vol. % |
| Heart Rate | Polar HR® Set | |
| | 3-Channel ECG (optional)<br>12-Channel ECG (optional) | |

### TELEMETRY

| | |
|---|---|
| Type | Bidirectional 19200 Baud |
| Frequency | 433 - 424 MHz |
| Range | 1000 m |
| Interface | RS232 |

### PHYSICAL SPECIFICATIONS

| | |
|---|---|
| Dimensions (LxWxH) | 2x (120x110x45 mm) |
| Weight | 570 g (without Battery) |

### ELECTRICAL SPECIFICATIONS

| | |
|---|---|
| PC Interface | Serial (RS232) |
| Power Supply | Battery Internal 7.2 V nominal, 2200 mA |

### OPERATING CONDITIONS

| | |
|---|---|
| Warm-Up Time | approx. 30 min |
| Temperature | - 10° to max. +40° C |
| Ambient Pressure | 500 - 1050 mbar |
| Relative Humidity | 0 - 99 % (non-condensing) |

### PRODUCT SAFETY

- Directive 93/42/EEC
- DIN EN 14971
- DIN EN 60601-1 / 60601-1-1 / 60601-1-2 / 60601-1-4
- CE 0124

### QUALITY MANAGEMENT

- Directive 93/42/EEC; Annex II; Section 3
- EN ISO 9001
- EN ISO 13485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CORTEX
Medical · Sports · Fitness

# MetaSoft® Studio

## One Software for all Processes

All CORTEX systems are based on the application software MetaSoft® Studio. It controls and monitors all processes of Cardiopulmonary Exercise Testing and all peripheral systems, e.g. heart rate and blood pressure measuring tools and ergometers.
A clearly structured user guidance is provided based on intuitive workflows. MetaSoft® Studio can be operated via keyboard, mouse or touch screen.

## SOFTWARE OPTIONS

- CORTEX MSS Training Guidance
- CORTEX MSS Exercise Scheduler
- Activation License - mc 3000 Interface
- CORTEX MSS 12-Channel ECG Interface
- CORTEX MSS Spirometry
- CORTEX MSS Metabolism for CPET
- CORTEX MSS Basal Resting Metabolic Rate
- CORTEX MSS Interpretation Assistant by Wassermann
- CORTEX MSS Pre-operative Risk Assessment
- CORTEX MSS Risk Assessment for heart failure patients
- CORTEX MSS HL7 Interface
- CORTEX MSS Import Function AIRCHECK

## MINIMAL REQUIREMENTS

COMPUTER / NOTEBOOK

| | |
|---|---|
| · Processor | Intel Core 2 Duo / 2 GHz, AMD Athlon 64 X2 / 2 GHz or higher |
| · Graphics | DX9 compatible, with 128 MB RAM or higher |
| · Screen | 1280*1024 (4:3), 1280*800 (16:9) |
| · Hard disk | > 20 GB |
| · Drive | DVD-ROM |

WINDOWS OPERATING SYSTEMS

- MS Windows® XP (SP3)
- MS Windows® Vista (32, 64 Bit)
- MS Windows® 7 (32, 64 Bit)
- MS Windows® Server 2008 (32, 64 Bit)

INTERFACES

- LAN
- min. 2x USB
- seriell 2x COM

OPTIONAL

- Sound Card
- CD / DVD Writer

## SUPPORTED DEVICES

BICYCLES ERGOMETERS

- custo med ec3000, ec500
- Daum ergo-bike Cardiopro, Medical, Premium
- Elmed EGT
- ERGO-FIT CYCLE, EF
- Ergoline Ergometrics / ErgoSelect
- ERM-100
- Fukuda BE-350, -360
- GE eBike
- h/p/cosmos compatibele
- Kettler CX1
- Lode Corival / Examiner / Excalibur/ Rehcor
- MIHA ProCycle
- Monark 829, 839
- Proxomed Kardiobike
- RBM Cyclus
- Seca CT 100
- Technogym BikeMed, KRace
- Other Devices

ARM ERGOMETERS

- Lode Anglo

TREADMILLS

- Cardioline CardioTread
- Daum ergo_run
- Ergo-fit Cadio Trac
- Fukuda MAT
- Gait Trainer 2
- h/p/cosmos Compatible, Mercury, Pulsar, Quasar Saturn, Stellar, Stratos, Venus
- Jaeger CosCom
- JNB JT4000M
- Lode Valiant
- Marquette T2000
- Micromed Centurion
- Quinton ST
- TaeHa TH
- Technogym Excite Run, RunRace
- Trackmaster TM, 425, TMX
- VR3000
- Woodway PPS 55 Med, USA, XELG
- Other Devices

ECG SYSTEMS

- AmedTec ECG Pro
- custo med custo diagnostics, custo card / meta control 3000
- Fukuda stress
- GE CardioSoft, CASE
- Micromed Elite
- Mortara/Xscribe M12A-USB
- Spacelabs CardioNavigotor, Sentinel

BLOOD MEASURING SYSTEMS

- SunTechTango, Tango+

OXYGEN SATIETY MEASURING SYSTEMS

- Nonin 4100 Bluetooth Oxymeter, Xpod/Ipod



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## Annex 6 – Compact Evolution of Wheelchair pointed by Carriel (2007)

Fig.24: Chinese sarcophagus dating from 525AD

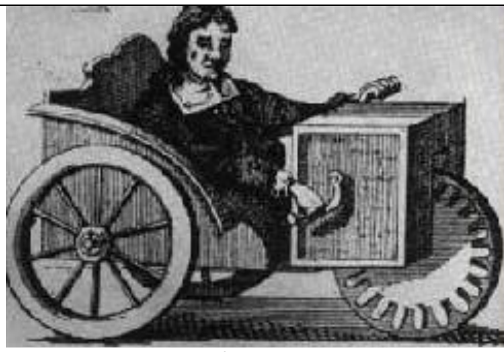

Fig.25: Stephen Farfler in his own WC (1655).

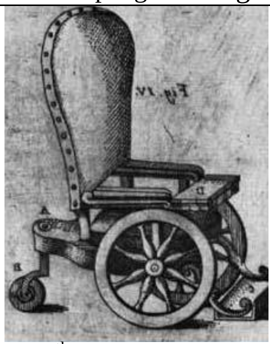

Fig.26: End of 18th century, called *“Seating”* WC.

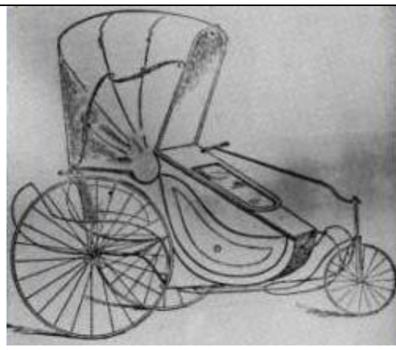

Fig.27: John Dawson WC, England 1783.

Fig.28: From left to right: tricycle, WC and bycicle.

Fig.29: 19th century wheelchair.

Fig.30: Wheelchair made of wood, 1894.

Fig.31: WC with a seat made of weaved fiber.

Fig. 32: 1930 WC made of steel tubes.

Fig.33: 1st “X” WC, U.S. patent by E&J.

Fig.34: “*Impulse Racing WC”*, E&J, EUA (1986).

Fig.35: “*Champion 3000”*, Paratec AG, Suíça (1986).

Fig. 36: Basketball WC, from Invacare Homecare.

Fig.37: Brazillian orthostatic WC.

Fig.38: German orthostatic WC.

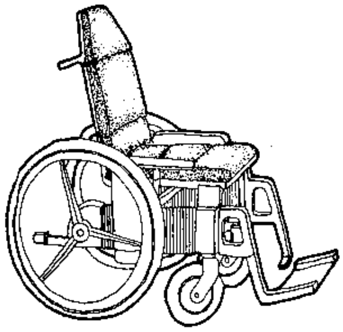

Fig.39: Elderly WC Model with segmented sit.

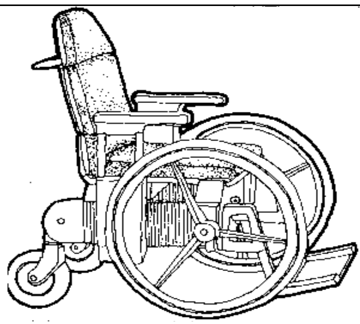

Fig.40: Elderly WC frontal traction model.

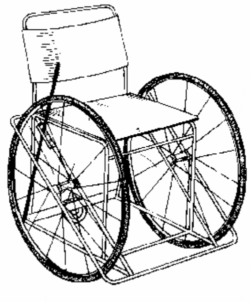

Fig. 41: Huckstep wheelchair model Ilustration.

Fig. 42: WC developed by “Free Wheelchairs Mission”.

Fig. 43: Motivation WC “Mekong”.

Fig. 44: The Yamaha WC "JW-II” (2000).

Fig. 45: Model “Freedom S” motor driven WC.

# Annex 7 - Alpine Skiing for Handicapped

Fig.46: Monoski inpired in ski sled (Nowak, Comeback – *Sport für Behinderte*, 1988).

Fig.47: Monoski 80’s, ski for handicapped (Nowak, Comeback – *Sport für Behinderte*, 1988).

Fig.48: Monoski (Nowak, Comeback – *Sport für Behinderte*, 1988)

Fig.49: Cross country sledge (Comeback – *Sport für Behinderte*, 1988).

Fig.50: New generation of cross country sledge (www.praschberger.com).

Fig.52: Sit-ski, Lacome, U.S. patent 2000.

Fig.53: “Mono-ski” (www.praschberger.com).

Fig.54: Monoski “bullet” (www.praschberger.com).

*Curricullum Vitae*

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**Master Degree in Human Kinetics Science & Commercial Pilot**

| | |
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| **1985** | **Concluded the High school in Porto Alegre, Brazil** |
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