Phonological and Semantic Overlap Between Words: Effects on Recognition of Familiar and Recently Acquired Words in Early Childhood

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Preliminary Note

The current thesis is presented in a traditional dissertation format; it is composed of three empirical studies that I carried out during 2014 and 2018. Chapter III encloses a copy of the original article published in *The Journal of Experimental Child Psychology* regarding the first study. Chapters IV and V consist of the manuscripts that are under preparation about the remaining two studies.

Avila-Varela, D. S., Arias-Trejo, N. & Mani, N. (2021). A longitudinal study of the role of vocabulary size on priming effects in early childhood. *Journal of Experimental Child Psychology, 205*, 105071. doi:10.1016/j.jecp.2020.105071.

Avila-Varela, D. S., Jones, G. & Mani, N. (*in preparation*). Effects of words' phonological and phono-semantic overlap in toddlers' word recognition.

Avila-Varela, D. S., Hartman, T. & Mani, N. (*in preparation*). Effects of words' phonological and semantic overlap in novel word recognition.

I served as the first author in these three manuscripts since it was my responsibility to (i) develop the rationale for the studies, (ii) design and conduct the experiments, (iii) analyse and interpret the data, and (iv) write up the manuscripts. The work was carried out with the support of my dissertation supervisor, Prof. Dr. Mani, who advised me along this process. Although, the experiment for the second study was conducted at the Nottingham Trent University (Great Britain) in collaboration with, and under the supervision of, Prof. Dr. Gary Jones.

Despite not being part of the current dissertation, as the product of my efforts to stablish fruitful collaborations with other researchers, I have been involved in works leading to other four manuscripts; all of them already published in international peer-reviewed journals. Two of these manuscripts are on the field of ***language acquisition***, same as the present dissertation:

Arias-Trejo, N., Angulo-Chavira, A. Q., **Avila-Varela, D. S.**, Chua-Rodriguez, F., & Mani, N. (2022). Developmental changes in phonological and semantic priming effects in Spanish-speaking toddlers. *Developmental Psychology*, 58(2), 236–251. DOI: 10.1037/dev0001290.

Jones, G., Cabiddu, F., & **Avila-Varela, D. S**. (2020). Two-year-old children's processing of two-word sequences occurring 19 or more times per million and their influence on subsequent word learning. *Journal of Experimental Child Psychology, 199,* 104922. DOI: 10.1016/j.jecp.2020.104922.

The remaining two publications are related to topics besides language acquisition:

De Filippi, E., Uribe, C., **Avila-Varela, D. S.**, Martínez-Molina, N., Pritschet, L., Santander, T., Goard Jacobs, E., Kringelbach, M. L., Sanz, Y., Deco, G. & Escrichs, A. (2021). The menstrual cycle modulates whole-brain turbulent dynamics. *Frontiers in Neuroscience, section Brain Imaging Methods.* DOI: 10.3389/fnins.2021.753820.

Martínez, P. M., Miró, E., Sánchez, A., Lami, M., Prados, G., & **Ávila, D**. (2014). Spanish Version of the Pain Vigilance and Awareness Questionnaire: Psychometric Properties in a Sample of Women with Fibromyalgia. *The Spanish Journal of Psychology, 17*, E105. DOI: 10.1017/sjp.2014.108..

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Barcelona, February 21st, 2022
Daniela Susana Avila-Varela

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Abstract

Classical research on word recognition describes how when adult participants are presented with pairs of words that share phonemes or belong to the same semantic category, the processing of the second word is facilitated provided the first word is related to the second. These observations have suggested that words in the mental lexicon are connected via phonological and semantic links. However, more recently, these association rules have been found to evolve in children during the early phases of language acquisition, at the time in which their language processing skills are being developed together with a fast growth of the child's vocabulary.

The present dissertation deals with the phenomena of facilitation and interference in word recognition due to phonological and semantic similarities during early childhood. It does so through three interrelated studies. In a longitudinal design, the first study investigated whether phonological and semantic priming would be better predicted either by the infants' vocabulary size or by their age. The second study investigated the impact of joint phonological and semantic similarities on word recognition. While past studies had investigated both factors separately, Study II investigated the impact of both factors in combination. The third and last study dived into the question of how word recognition is affected by the similarities among the novel words to learn. Therefore, the mechanisms of facilitation/interference of word recognition due to phonological and semantic overlap was again investigated in young children, but under controlled learning experimental protocol; comparing the effects of word overlap on recently acquired words.

Overall, the results of this dissertation show that (i) word recognition is primarily modulated by the number of words in the mental lexicon of children, (ii) phonological interference of word recognition can be alleviated by introducing a semantic similarity, and (iii) that children recognise better recently acquired words when the novel words shared either phonological or semantic similarities. Result (i) provides the first evidence of the effect of children current vocabulary on phonological interference effects. These results align with models of spoken word recognition that suggest that during speech processing, phonologically related words are activated and compete for recognition in line with the *Cohort Model* and the *Neighbourhood Activation Model*; thus, the more words a child knows more related associates are activated. In addition, result (ii) shows that adding a similarity in meaning reduces the interference in target recognition induced by the phonological similarity between words. These results resonate with the *Distributed Cohort Model*, which suggests that semantic aspects of words reduce the activation of phonologically related words to the target supporting the recognition of the intended word. Finally, together the results of this dissertation highlight the differential impact of words simple vs. compound overlap on familiar and recently acquired words. Specifically, it was found that while simple phonological or semantic similarities interfered with familiar word recognition, simple similarities between novel words supported novel word recognition. These results support the hypothesis of the *LEX model of word learning* that predicts better learning of novel words of similar form or similar meaning than of words with similar form and meaning.

Chapter I. Introduction

A *spoken word* can be defined as a sequence of phonemes that convey meaning; for example, the word “dog” is formed by the phonemes /d/, /ɒ/, and /g/, and it is used to designate a domestic animal covered with fur, with four legs that belongs to the taxonomic category mammal. The word "dog" can be heard in speech together with other words such as “bone” or “ball”. The information associated with “dog” is stored in the long-term memory, in the mental lexicon (Pisoni & Luce, 1987). When we talk about the *phonological domain*, we refer to the phonemes that constitute the label (in the example, the phonemes /d/, /ɒ/, and /g/). Similarly, when we talk about the *semantic domain*, we refer to the features associated with the concept referred to by the word; for example, the information associated with the concept “dog” (e.g., “a domestic animal”, “with fur”, “with four legs”, and “belonging to the taxonomic category mammal”).

Classically the ***priming paradigm*** has been implemented to investigate the process that mediates word recognition. In this paradigm, related ***prime*** and ***target*** stimuli are presented in rapid succession to study the impact of the overlapping information between the prime and the target on the response to the target. Research applying this paradigm assumes that the prime’s influence the response to a target is an index of the links between the words in the mental lexicon. On the one hand, research applying the priming paradigm has been concerned with studying the impact of the ***phonological overlap between words*** (Slowiaczek & Hamburger, 1992; Slowiaczek et al., 2000; Slowiaczek et al., 1987; Goldinger et al., 1992). In these studies, words are presented to the participants that overlap at the onset (e.g., “dog” and “door”, which share the onset phoneme /d/), or at the rhyme (e.g., “dog” and “fog”, which share the rhyme phoneme /g/) (e.g., Slowiaczek et al., 2000). The experiments have found an effect of the degree of overlap between the two words; that is, increasing the number of shared phonemes between words from zero to three reduces the time that it takes the participants to recognise the targets (Slowiaczek et al. 1987).

On the other hand, the priming paradigm also has been used to investigate the impact of the ***semantic overlap between words*** on word recognition; presenting prime and target words that overlap in their meaning (Meyer & Schvaneveldt, 1971; Marslen-Wilson & Zwitzerlood, 1989). For instance, Meyer and Schvaneveldt (1971) carried out a lexical decision task in which participants were presented with two strings of letters simultaneously, one above the other. In this task, participants had to decide whether the two strings were real words or not. The authors presented pairs of words that were either associated (e.g., “bread”-“butter” or “nurse”-“doctor”) or unassociated (e.g., “bread”-“doctor” and “nurse”-“butter”) according to the Connecticut Free Association Norms (Bousfield et al., 1961). Participants were faster at deciding that both words were real if they were and slower if the two words were unrelated.

These two example, together with reports from many other studies, have evidenced that words are linked to one another in the mental lexicon of adults based on phonologic and semantic overlaps between them, and that their associative links modulates word recognition. A relevant matter that has received much attention in the past years is then to comprehend how the mental lexicon and the phonological / semantic ties between the words form during early childhood (Chow et al., 2017). In this regard, particular questions have emerged. For example, how does the modulation of word recognition due to phonological and semantic similarities between words vary across development? Does the single overlap – either phonological or semantic – affect word recognition differently from the combined overlap – phonological and semantic? How does the phonological and/or semantic overlap between words affect word learning during development, at the time children undergo a fast growth of their lexicon?

This dissertation presents three studies that were aimed at investigating those questions. The three studies are summarised in Chapter II and detailed, one-by-one, in Chapters III to V. The remaining of this introductory chapter is dedicated to review the methodological foundations and the state of the art knowledge in the field. Section A provides a literature review on relevant empirical findings in spoken word recognition in early childhood. Section B outlines relevant empirical findings found in children applying the priming paradigm. Section C summarises empirical findings on young children’s recognition of recently acquired words. Finally, Section D examines theoretical models of word recognition and word learning.

I. A. Definitions and empirical evidence of word recognition

According to Pisoni and Luce (1987), ***lexical access*** comprises “those processes that are responsible for contacting the appropriate lexical information in memory once a pattern match has been accomplished. Lexical access, then, is that process by which information about words stored in the mental lexicon is retrieved” (p. 13). According to the authors, ***word recognition*** is defined as “those processes responsible for generating a pattern from the acoustic-phonetic information in the speech waveform and matching this pattern to patterns previously stored in memory (i.e., for words) or to patterns generated by rule (i.e., for pseudo-words)” (Pisoni & Luce, 1987, p. 13). Thus, word recognition is a process focused on matching the heard speech signal to stored sound patterns in memory, which is especially relevant to determine whether a string of sounds constitutes a “real” word or not, while lexical access, on the other hand, is a process of retrieving certain content associated with words.

Now, it is essential to differentiate these concepts from ***word learning***, which is the process of storing new label-meaning associations in the long-term memory. Although word recognition and word learning involve different processes, both need to “access” the knowledge already stored in the long-term memory. Also word recognition focuses on retrieving an intended meaning, while word learning focuses on storing information. Nevertheless, lexical access and word learning can overlap in infancy because each encounter with a word may serve the child both to recognise words and to add new information about a stored word or concept. However, in this dissertation, recognition of familiar words (words that children have encountered previously) and recently acquired words (words that children encounter for the first time) are studied separately.

Word recognition skills across development

A starting point in studying children’s skills to recognise spoken language was to describe and quantify which words children understand at different ages. A classic tool used to study vocabulary development is the MacArthur Communicative Development Inventories (CDIs, Fenson et al., 1994), which are aimed at quantifying the infant's lexicon through parents' reports. The CDIs includes a list of approx. 600 words, and for each one, caregivers indicate whether the child knows (passively comprehends) or says (voluntarily produces) them. As an output, the total receptive and productive vocabulary size of the child can be estimated. The *Fragebogen zur frühkindlichen Sprachentwicklung* (FRAKIS; Szagun et al., 2009) is the German adaptation of the origianl North American English CDI. Initial research applying the CDIs found that the first evidence of word comprehension appears between 8 and 10 months of age, followed by an increase of productive vocabulary between 10 and 30 months of age (Bates & Goodman, 1997; Fenson et al., 1994; Szasgun et al., 2006).

The infant lexicon through the looking behaviour

Subsequent research developed the intermodal preferential looking paradigm (IPLP; Golinkoff et al., 1987) to study young children's spoken word recognition. In this paradigm, children see two images displayed side by side on a screen (e.g., the image of a "book" and a "cookie"), then the name of one of the images is heard (e.g., "Look, at the book!") (see Figure 1).

Figure 1

The intermodal preferential looking task. Here the teddy bear represents a fictitious participant.

In the intermodal preferential looking paradigm, word recognition is typically assumed in the natural behaviour of the participant to fixate on the matching referent (in the example, to look at the image of the "cookie" upon hearing the label "cookie") rather than the mismatching image (the image of the "book" in the example). Initially, when the IPLP task started to be implemented, children's looking behaviour used to be video-recorded and manually coded offline, yet recent technology such as eye tracking automatically records children's gaze behaviour. Word recognition is typically quantified with the formula PTL = TL/(TL+DL), where the proportion of target looking (PTL) is obtained as the time participants spend looking at the target (TL) compared with the time they looked at it and at the distractor (DL). Thus, word recognition is indexed by higher target fixations than distractor fixations.

By applying the intermodal preferential looking task, evidence found that children recognise their first words around 6 to 9 months of age (Bergelson & Swingley, 2012, 2015; Kartushina & Mayor, 2019). In addition, research has found a correlation between age and both speed and accuracy of word recognition, i.e., as children grow up, they need less time to drive their gaze towards the matching image for the spoken word, and they start to fixate on it before hearing the complete target word (Fernald et al., 1998). Specifically, in Fernald et al.'s (1998) study, it was found that while before 15 months of age children's word recognition begins after the complete target word is presented, from 18 to 21 months of age, children are on average 300ms faster at starting to fixate on the target picture, and also this target fixation starts before hearing the complete target word. Thus it was shown that with age, children become faster at driving their gaze to a matching referent, and they are more efficient at recognising words as they can rely solely on the initial segments of the label to start to identify the plausible referent to it. In addition, it was found that by two years of age, children rapidly shift the object they are fixating on, according to the input they hear; e.g., if they see a picture of a "dog" and a "doll", and they were looking at the dog, when they hear the /l/ they switch their gaze to the other picture (Swingley & Fernald, 2002). These results suggest that as children grow, they become more efficient at processing and recognising familiar words.

I. B. The priming paradigm and the study of the lexicon

The rationale of implementing a priming task to study the lexicon is that it is typically assumed that an influence of the prime stimuli on target responding is an index of links between words in the early lexicon, and ultimately it provides information about how the mental lexicon is organised in the toddler's mind. When applying this paradigm, facilitation occurs when faster or more accurate target recognition is found when previously a related prime was presented than unrelated. In contrast, interference is indexed by slower or less accurate target recognition when previously a related prime was presented.

Phonological priming in adults

One of the studied links connecting words in the mental lexicon is based on overlapping phonemes between words. For example, it is assumed that the words "dog"/dɒg/ and "door"/dɔː/, which share the onset /d/, are linked in the mental lexicon based on that shared phoneme similarity.

Evidence applying the priming paradigm with adults shows that a word is recognised faster if previously a phonologically related word was presented. For example, the presentation of the word “door” supports the recognition of the spoken word “dog” given their shared onset /d/, and it is assumed that the prime word “door” pre-activates the target word “dog”, facilitating its recognition (Slowiaczek & Hamburger, 1992; Slowiaczek, Nusbaum & Pisoni, 1987; Goldinger, Luce, Pisoni & Marcario, 1992).

Furthermore, it was found that increasing the degree of overlap between the words presented in immediate succession makes target recognition faster (Slowiaczek et al., 1987). In their study, Slowiaczek and collaborators (1987) found that the recognition of the target word (e.g., “sense”) improved with an increase in the number of shared phonemes between it and the prime word (e.g., “safe”, 1 phoneme; “said”, 2 phonemes; “send”, 3 phonemes), thus indicating that the greater the phonological overlap between words the greater the improvement in target recognition.

Nevertheless, word recognition is not always improved when prime and target overlap phonologically (e.g., Radeau et al., 1989; Slowiaczek & Pisoni, 1986). For instance, Slowiaczek and Pisoni (1986) only found facilitation in a lexical decision task when the prime and the target words were identical, but not when words shared word-initial phonemes.

In addition, there is evidence of effects on word recognition depending whether the person knows a larger or smaller number of similar-sounding words. Thus, some studies report slower recognition times of words from dense neighbourhoods (i.e., words with a large number of similar-sounding words) than for words from sparse neighbourhoods (i.e., words with few similar-sounding words) (Goldinger et al., 1989; Luce & Pisoni, 1998; Vitevitch & Luce, 1998). This suggests a modulation of word recognition based on the number of similar-sounding stored words in the mental lexicon.

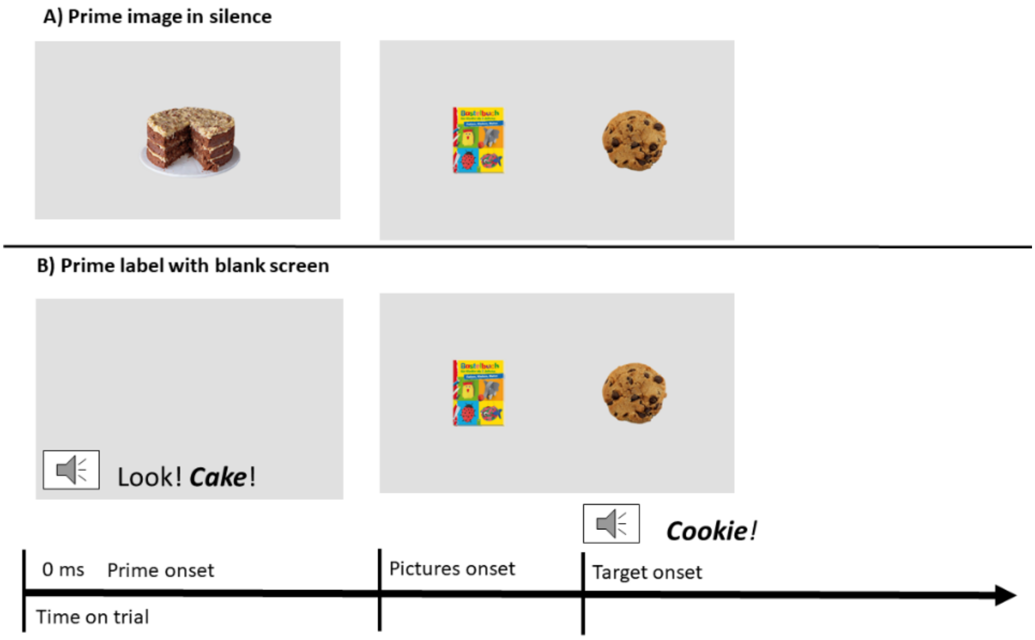
Finding facilitation and interference in word recognition when presenting similar-sounding words has been linked with the levels of representation involved (Hamburger & Slowiaczek, 1996; Vitevitch & Luce, 1998). In priming tasks *facilitation* effects can be caused by the overt phonological overlap between labels presented in quick succession; thus, these effects may occur at the sub-lexical level of representation, where acoustic information (e.g., phonotactic probabilities or phonemes) is automatically processed. In contrast, *interference* could result from the competition of phonologically related words activated at a lexical level, where abstract information associated with words is processed (see Marslen-Wilson & Zwitserlood, 1989). Thus, finding *facilitation* or *interference* in phonological priming tasks indicates that words are organised in the mental lexicon under phonological links because the presence of a phonologically related/unrelated prime systematically modulates target recognition.

Phonological priming in young children

Given the rapid increase in the linguistic skills of children during the first year of life, phonological and semantic priming effects have also been investigated in young children. In order to investigate thise processes, the intermodal looking task has been adapted to the priming paradigm to study how the relatedness between words impacts word recognition. In this adaptation, before the images are displayed on the screen, a prime stimulus is presented. The prime stimulus is a stimulus presented shortly before the target label and is related to it somehow (e.g., both words share phonemes or have associated meaning). The prime stimulus can be an image presented in silence or the name of an object, heard without its image (see Figure 2).

Figure 2

Priming Adaptation of the Intermodal-Preferential-Looking Task. A) Design where the prime stimulus is an image displayed in silence. B) Design where the prime stimulus is an audio of a prime word presented with a blank screen.



Research with infants applying the itermodal preferential looking task adapted to the priming paradigm report phonological facilitator and interference effects on word recognition when words share the onset (Mani & Plunkett, 2010, 2011). For instance, Mani and Plunkett (2010) presented a priming task, where the image of a prime appeared in silence before a target was named (see Figure 2A). The authors found that at 18 months of age, children looked faster and longer at the target image (e.g., “cup”) when it was preceded by a phonologically related prime (e.g., “cat”, as “cat” and “cup” share the onset /k/) than with an unrelated prime (e.g., “teeth”). Nevertheless, at 24 months of age, children look longer at the target when an unrelated prime precedes it than when a related prime precedes it (i.e., interference effects) (Mani & Plunkett, 2011). One explanation suggested by the authors for the interference effects found in the 24-month-old children is the increasing number of phonologically similar-sounding words (cohort size) known by older children. This suggestion was further supported by the finding that phonological interference effects are mediated by the cohort size of prime and target words (Mani & Plunkett, 2011). These findings highlight a developmental trend in which children develop inhibitory links among phonologically related words in their mental lexicon by the end of their second year.

However, given that the studies reviewed here are cross-sectional (i.e., participants were tested at different ages), some variables associated with the cohort of participants (e.g., differences in vocabulary size, attentional levels) may have impacted their performance vanished. Therefore Study III investigate phonological priming effects across development in a longitudinal study (see section “The effect of vocabulary size on word recognition” for an extended rationale).

Semantic fcilitation on familiar word recognition

Children younger than two years have shown facilitation on recognition of semantic related words in studies implementing different methodologies, such as the intermodal preferential looking task (Bergelson & Aslin, 2017) or the heard turn preference (where lists of related/unrelated words are presented, Delle Luche et al., 2014).

Nevertheless, applying the priming paradigm yielded no evidence of semantic facilitation in word recognition at 18 months of age (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009). In those studies the results found similar target looking (e.g., "dog") when preceded by a semantically related (e.g., "cat") or by an unrelated prime (e.g., "plate"). Later, at 21 months of age semantic facilitation was found for words related associatevily and taxonomically (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009). A taxonomic link refers to words that belong to the same category (e.g., "elephant"-"dog"), while an associative link refers to pairs of words with high associative strength according to free association norms (e.g., "bone"-"dog"). In this case, it was found that children aged 21 months showed higher target looking (e.g., "dog") when the word was preceded by a taxonomically and associatively related prime (e.g., "cat") than when it was preceded by an unrelated prime (e.g., "plate"). By the second year of life toddlers show pure associative or taxonomic facilitation (Arias-Trejo & Plunkett, 2013). That is, at two years of age, participants looked more at a target (e.g., "monkey") when it was preceded by either a purely taxonomic (e.g., "lion") or a purely associative prime (e.g., "banana") than when an unrelated prime was presented (e.g., "chair").

The inconsistent pattern of results of sensitivity to semantic relatedness between words before and at 18 months of age (Bergelson & Aslin, 2017; Borovsky & Peters, 2019; Delle Luche et al., 2014) and priming studies that do not find indexes of sensitivity to semantic links at this age (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009) might be driven by the different methodologies applied. That is, the studies applying the priming paradigm (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009) might have imposed higher processing demands than the experimental paradigms applied in the other studies, where either simple intermodal preferential looking or the head turn preference procedure was implemented.

Semantic interference on familiar word recognition

More recently, *toddlers' interference* in *target recognition* has also been studied, by implementing a backward semantic inhibition paradigm (Chow et al., 2016). In this paradigm, an intervening stimulus between the prime and the target is presented; it could be either a word (labelled and accompanied by its image) or a tone (accompanied by the image of a chequerboard). Next, the target and distractor images are presented side by side, and the target label is named. For example, for the semantically related pair "chair"-"table", and the unrelated pair "coat"-"table", the intervening stimulus is the word "chicken" or a tone. Applying this paradigm, it was found that 24-month-old toddlers looked more at the target (e.g., "table") in the semantically related condition (than in the unrelated condition, i.e., facilitation effect) when the intervening stimulus was a tone. On the other hand, target recognition was higher in the unrelated than in the semantically related condition (i.e., interference effect) when the intervening stimulus was a word. Altogether the results show that when the intervening stimulus was a tone, semantic facilitation was found (i.e., participants looked more at the target in the semantically related condition); and when it was a word, a backward semantic inhibition was observed (i.e., participants looked more at the target in the unrelated condition). Here, semantic inhibition occured when the semantic processing of the intervening stimulus (e.g., “chicken”) is required, breaking the active link between the semantically related items (e.g., “table-chair”).

In a different study, the authors found that in a sample of 18-month-old children, those with a larger vocabulary looked more at the target in unrelated trials than in the semantically related trials when the intervening stimulus was a word (i.e., showing backward semantic inhibition on word recognition). These results indicate that inhibitory processes are closely related to vocabulary growth. As suggested by the authors, as the number of lexical items increases, the need to develop an adult-like word recognition system organised around activation and inhibition links between words also increases.

Finally, a recent study found also interference effect on word recognition when 18- to 20-month-old toddlers were presented with semantically related words (Lo et al., 2021). The children were given a comprehension task in which they heard a target and saw two images (a target and a distractor) on a touch screen. In the study, children showed higher accuracy tapping the target in the unrelated than in the semantically related condition. These results suggest that upon hearing the target, related words were co-activated, thus competing with the target for recognition and interfering with target recognition.

Overall the results suggest that children show semantic facilitatory and interference effects on recognition before the second year of life (Bergelson & Aslin, 2017; Borovsky & Peters, 2019; Delle Luche et al., 2014; Lo et al., 2021). More recent research suggests that those effects are mediated by children’s vocabulary size (Borovsky & Peters, 2019, Chow et al., 2019). However, as all the studies on semantic priming are cross-sectional, it can not be ruled out that the effects are determined by the vocabulary of the age of the participant. Therefore, in study III the role of vocabulary size while controlling for age (longitudinal design) in contexts of semantic overlap in word recognition is examined.

Phono-semantic similarities on familiar word recognotion

Phonological and semantic lexical links have also been simultaneously examined in word recognition studies applying the visual world paradigm with adults (Allopenna et al., 1998; Huettig & McQueen, 2007; Yee & Sedivy, 2006) and children (Chow et al., 2017 Huang & Snedeker, 2010). These studies find that, upon hearing the target, initial fixation goes to images of phonologically related words, followed by fixations toward images of semantically related words. These results indicate that, during word processing, initially phonologically related words to the target are accessed, and subsequently semantically related words are accessed.

Additional research found that also 2-year-old children show activation with phonologically and semantically related words (Altvater-Mackensen & Mani, 2013a; Angulo-Chavira & Arias-Trejo, 2018, 2021; Mani et al., 2012). Those studies instead applied the intermodal preferential looking task adapted to a mediated priming paradigm where only two images are displayed (and not four as in the visual world paradigm). In Mani and collaborators’ study (2012), 2-year-old children were presented with a prime stimulus that was phonologically related at the onset (Exp. 1) or at the rhyme (Exp. 2) to a mediating word, which was semantically related to the displayed target image. Here, for example, the only way for a word like “clock” to facilitate the recognition of the word “shoe” is through the activation of the phono-semantically related word “sock”. The results show that 2-year-old children, like older children and adults, also display phono-semantic priming effects. Furthermore, a mediated priming study by Altvater-Mackensen & Mani (2013a) found that the recognition system of 2-year-old children is flexible enough to activate the correct version of a word upon hearing it mispronounced (e.g., “cat” when hearing “gat”), based on the phonological overlap with the final phonemes of the word), and then activate semantically related words to this word (e.g., “dog”). These results show a cascading mental activation flow from the mispronounced prime to the correct label (through the phonological overlap between them) and then towards the semantically related mediated word and the target (by the semantic overlap between the correct word and the target).

More recently, a mediated priming study by Angulo-Chavira & Arias-Trejo (2018) with Spanish-speaking toddlers found a bidirectional activation between semantic and phonological word associates. Also, they found that a prime image (e.g., “dog”) activated a semantically related word (e.g., “cat”), which then facilitated the recognition of a phonologically related target (e.g., “cup”), yet only in older children, of 30 months of age. This result indicates that while cascaded activation from phonologically to semantically related words occurs at 24 months, the reverse order of activation (i.e., activation from semantically related words to phonologically related words) is possible only from 30 months of age. Overall, research applying the additive priming paradigm informs about ***which type of links*** connect words in the mental lexicon (e.g., phonologic, semantic);. In contrast, studies on phono-semantic links contribute to an understanding regarding ***the order/sequence*** in which those links or routes are activated during speech processing (e.g., first activating phonological links followed by semantic links).

In addition, in mediated priming studies, although phonologically and semantically related words are activated, and activation requires two steps for recognition, involving different levels of representation (e.g., phonological-semantic, Mani et al., 2012; Altvater-Mackensen & Mani, 2013a; Angulo-Chavira & Arias-Trejo, 2018). Specifically, in a mediated priming task, the prime stimulus (e.g., “cup”) activates a phonological associate (e.g., “cat”). Thus, in the first phase the phonological associate is activated in response to the prime stimulus. Then, the recognition of the target word (e.g., “dog”) is measured. In this case, the recognition of the target word is modulated by the semantic link between the mediated word “cat” and “dog”. So, in a mediated priming task, two phases of processing are involved. There is an initial phase of processing in which phonologically related words are activated, and a second phase in which semantically related words are activated (e.g., Mani et al., 2012; Altvater-Mackensen & Mani, 2013a). The reverse pattern of activation was also found in Angulo-Chavira & Arias-Trejo (2018), where semantically related words are activated at an initial stage, followed by phonologically related words at a subsequent stage of activation.

Nevertheless, applying the additive priming paradigm will allow us to study the impact of combined phonological and semantic overlap between words on recognition at the same phase/stage of processing. Also, in doing so, it will be possible to compare how the combined sources of overlap (phonological and semantic, e.g., “turkey”-“turtle” words that share phonemes and category) impact recognition compared to when only one source of overlap is presented. Here, lower interference is expected from phonological and semantic overlap than from phonological overlap alone, as the added semantic overlap may have narrowed down the activated competitors for recognition. Therefore, in Study II, target recognition is tested in an additive priming paradigm where a phono-semantic-related priming condition and a simple phonological condition are compared.

The effect of vocabulary size on word recognition

Children's vocabulary size is one of the main variables linked with language processing skills (Fernald & Marchman, 2012; Lany, Giglio & Oswald, 2018; Borovsky & Peters, 2019; Fernald, Swingley & Pinto, 2001). For instance, studies with infants have found a correlation between early language skills, such as recognising words on fluent speech, lexical priming (Friedrich & Friederici, 2006; Junge et al., 2012) and other cognitive functions (Borgström et al., 2015) with later vocabulary development. Also, studies measuring children's vocabulary size have shown relationships between early vocabulary and subsequent academic outcomes (Bleses et al., 2016; Duff et al., 2015; Marchman & Fernald, 2008; Morgan et al., 2015), thus indicating that children's early vocabulary development might be related to individual differences in general learning performance.

One possible explanation for the modulation effect of vocabulary on speech processing might be because the more words a person knows, the more candidates can be activated during processing. Similarly, vocabulary size can modulate phonological and semantic priming effects because as the vocabulary size of the child grows; also grow the number of associates of words (related in form and meaning) that are activated during speech processing. Therefore, vocabulary size can also modulate phonological and semantic priming in word recognition, given that the more words someone knows, upon hearing a word, the more words associated with it that share phonemic or semantic features can be activated and compete for recognition.

Accordingly, as regards the role of vocabulary and phonological priming, a study with 2-year-old toddlers found impaired word recognition when previously a phonologically related word was presented; in addition, this interference effect was found to be modulated by the cohort and neighbourhood size of the target words used (Mani & Plunkett, 2011). Thus, the more words the child knew that sounded similar to the target, the more difficult it was for her to recognise the target image displayed on a screen.

Regarding semantic priming effects, no correlations with vocabulary size have been reported (Arias-Trejo & Plunkett, 2009, 2013).

However, a relation between children's vocabulary size and structure and their sensitivity to semantic relatedness among words was reported when applying an intermodal preferential looking task (Borovsky & Peters, 2019), a backward semantic inhibition paradigm (Chow et al., 2019), or when brain potentials were measured (Rämä et al., 2013). For instance, in Rämä et al. (2013), brain event-related potentials of 18- and 24-month-old children were recorded during a semantic priming task. The researchers found similar priming effects measured by brain potentials in 24-month-old children and in 18-month-olds with larger productive vocabulary sizes. This result indicates that 18-month-old children with an extensive vocabulary show equivalent priming effects to 24-month-old children. Thus, it is found that young children with large productive vocabulary sizes show a similar sensitivity to semantically related words as older toddlers.

Overall, the evidence reviewed here may suggest: first, the higher the efficiency to process language, the larger the child's vocabulary is; second, under phonological preparation, a larger vocabulary interferes with word recognition. When considering the interfering effect of larger vocabulary sizes on word recognition in priming studies, this relationship may be mediated by the increasing number of lexical entries in the mental lexicon.

However, most of the research looking at phonological and semantic priming effects in infancy has carried out cross-sectional studies where different samples of participants were tested at different ages (e.g., 18, 21 and 24 months); thus the contribution of particular participants' vocabulary size across ages may go unnoticed. Therefore, Study I presents a longitudinal design that allows us to control for individual variability in vocabulary size and age; thus, it will help disentangle their role in phonological and semantic priming effects on word recognition.

I. C. The role of phonological and semantic overlap on word learning

During infancy it can be considered that recognising and learning a word are the same process; with each encounter with a word, infants are learning new aspects of the association "label-meaning". For example, infants learn that "doggy" and "dog" designate the toy and the actual animal.

However, word recognition and word learning are different cognitive processes because learning (to some extent) needs recognition. That is, to learn a "new" label-referent association, it is required to recognise that this specific association is "not" stored in memory yet.

That said, it can be agreed that word recognition and word learning are closely interconnected processes (Borovsky et al., 2012; Borovsky et al., 2016a, 2016b; Borovsky & Peters, 2019; Ferguson et al., 2015; Fernald & Marchman, 2012). For instance, Fernald and Marchman (2012) found that late talkers who were more efficient at recognising familiar words at 18 months were also more likely to show accelerated vocabulary growth at 30 months of age than late talkers who were less efficient at early speech processing. The result highlights the interaction between current word recognition processing and later vocabulary size in children without typical language acquisition.

Specifically, in this work a distinction is drawn between recognising a familiar word and a recently acquired word, because the role of phonological and semantic overlap might be different during decoding (i.e., word recognition or lexical access of stored familiar words in the mental lexicon) and encoding (i.e., word learning or storing new content in the mental lexicon). Nevertheless, a possible mechanism to achieve this is through phonological and semantic links, as these links have been proposed to connect words in the mental lexicon (e.g., Meyer & Schvaneveldt, 1971; Slowiaczek & Hamburger, 1992; Collins & Quillian, 1969; Meyer & Schvaneveldt, 1976). Thus phonological and semantic links can be used, on the one hand, to access related familiar words, and on the other, to connect recently acquired label-referent associations with words already stored in the mental lexicon.

Regarding the role of phonological links in word recognition and word learning, in the work of Storkel and collaborators (2006) it was proposed that phonological links might facilitate the process of word recognition, while they might generate interference when integrating the novel mental representation in the memory. Concerning the role of semantic overlap in word recognition and word learning, facilitator effects have been reported (Arias-Trejo & Plunkett, 2013; Borovsky et al., 2016a, 2016b), thus suggesting a general beneficial role of semantic overlap between words in recognition and learning.

Given the fundamental role of lexical links in word recognition and word learning, the current dissertation aims to study the impact of phonological and semantic links in recognising familiar and recently acquired words. Thus, a review of the impact of those sources of overlap on word learning is presented next.

Phonological similarities on word learning

A study with 7-month-old infants has shown the beneficial impact of phonological overlap on word learning (Altvater-Mackensen & Mani, 2013b). In Altvater-Mackensen's study (2013), participants were initially pre-exposed to some words (e.g., "Löffel", Eng. "spoon"); and later, the detection of phonologically related novel words (e.g., "Löckel") and unrelated novel words (e.g., "Sotte") was measured while they heard fluent speech. Here, participants recognised better those novel words that sounded similar to the familiar pre-exposed words. This finding suggests that the phoneme sequence of the words presented during pre-exposure was activated in the following phase of fluent speech processing, which resulted in easier detection and segmentation of words that sounded similar to the familiarised words. This indicates that pre-exposure to a phonological pattern similar to a novel word to be learned facilitates its acquisition. Moreover, research found that 14-month-old children learn similar-sounding words (e.g., /bin/ and /din/) when the referent is highlighted during a learning phase (e.g., with clear sentential contexts and word-referent training) (Fennell & Waxman, 2010). Additional research with children between 18 and 23 months of age shows that they can learn similar-sounding novel words (Werker et al., 2002; Bailey & Plunkett, 2002; Swingley & Aslin, 2000). Along the same lines, studies of age of acquisition of words suggest that phonological features support word learning. For instance, a tendency to acquire novel words that sound similar to familiar words has been reported (Fourtassi et al., 2020; Storkel, 2004, 2009). Altogether this evidence suggests that phonological representations stored in the mental lexicon support learning of new words with similar phonological patterns to known words.

However, a study carried out by Nazzi (2005) with 20-month-old toddlers found that words that differed minimally at the vowel level were not learned (e.g., /pize/ and /paze), and that words that differed at consonant level (e.g., /pize/ and /tize) were more difficult to learn than novel words that sounded completely different (e.g., /pize/ and /mora/). These findings suggest that toddlers learn novel words that sound different from each other more easily than words that only differ at the consonantal level, while words that differ at the vowel level seem to be the hardest to learn. Thus, phonetically similar novel labels are challenging for children to learn when they only differ in one single vowel.

The contrariness of these findings can be explained if we consider Storkel et al.'s (2006) proposal, which suggests that phonological similarities impact differently on each aspect involved in word learning. On the one hand, phonological overlap might drive attention towards this overlap on the words involved, thus supporting learning. This suggestion is reinforced with the findings with regard to ease of segmentation in 7-month-old infants who segmented from speech novel words that sounded similar to pre-exposed words better than words that sounded different from pre-exposed words (Altvater-Mackensen & Mani, 2013b). On the other hand, phonological similarities can hinder the integration of the novel mental representation in the long-term memory – given the high degree of phonological overlap with mental representations of other similar-sounding words already stored. This aligns with Nazzi's (2005) results, which show that it was not easy for young children to learn similar-sounding words.

Moreover, the contrariness of the findings between Altvater-Mackensen and Mani's study (2013b) and Nazzi's (2005) study can be explained by the different processes tested in each of them. That is, while Altvater-Mackensen examined segmentation, Nazzi studied referent learning. Therefore, the results of Altvater-Mackensen talk about the role of phonological information in novel word segmentation (extracting single words from a fluent speech stream) and the results of Nazzi about referent learning (mapping between novel objects with novel labels). In addition, the difference in age of the participants tested, 7-month-old infants (Altvater-Mackensen & Mani, 2013b), 14-month-old toddlers (Fennell & Waxman, 2010) and older ones (Fourtassi et al., 2020; Nazzi, 2005; Storkel, 2004, 2009), could also explain the difference in results. Thus, the older the participant, the larger the number of words that can sound similar to the novel word to learn, so similar-sounding words already in her mental lexicon might interfere with integrating the recently acquired word there.

All that said, studies to date have not compared the effect of phonological overlap (between novel labels) and semantic overlap (between novel referents) on word learning. Therefore, in **Study III** novel word recognition in young children is tested under different learning conditions, where phonological overlap between novel labels and semantic overlap between novel referents to learn are controlled.

Semantic similarities on word learning

Regarding the impact of semantic overlap between words on word learning, it has been found that children display word recognition of familiar and newly learned words in categories in which they know a large number of other exemplars (e.g., “animals”, “body-parts”) better than in categories where they know fewer exemplars (e.g., “clothing”, “drinks”) (Borovsky et al., 2016a, 2016b; see also Peters et al., 2021). For instance, in Borovsky et al. (2016b), 24-month-old toddlers were taught novel words that according to parental reports belonged to high- or low-density categories. The “dense” categories were considered those in which children knew a large number of words (e.g., for the category “animal”, participants produced ME = 33.5 words in that domain). In contrast, low-density categories were those categories in which children knew few words (e.g., “clothing”; participants produced ME = 6 words in that domain). The findings showed that while participants recognised novel words in both high-density (e.g., “hedgehog”, a novel animal) and low-density categories (e.g., “banyan”, a novel clothing item), novel word recognition was more robust and accurate for novel words in high-density categories (i.e., “hedgehog”).Thus, these results talk of the leveraging effect that children’s previous knowledge of semantically related words has on familiar and novel word recognition. That is, learning can be facilitated by semantic similarities between a novel word and pre-existing mental representations of words stored in the mental lexicon. For example, the familiarity of a child with words referring to fruits (e.g., “banana”, “apple”, “orange”) can facilitate the learning of a novel label referring to a fruit she is encountering for the first time. Thus, for example, the learning of the novel label “mango” might be facilitated by her previous knowledge associated with other fruits (e.g., “sweet”, “small”, “eaten as a snack or dessert”).

However, studies to date have not explicitly looked at how combining phonological and semantic information modulates recognition of recently acquired words. Therefore, what remains unknown is whether the addition of phonological overlap to a novel label-referent association improves or impairs learning. Accordingly, **Study III** addresses this issue by comparing novel word recognition in young children when novel label-referent associations overlap only semantically and when they overlap phonologically and semantically.

Phono-semantic similarities on word learning

According to the leveraging perspective, word learning is facilitated when it is possible to recognise similarities between a novel lexical item and pre-existing concepts stored in the mental lexicon. In this way, previous knowledge may enable a learner to infer many aspects of a novel word's meaning. In this direction, facilitative effects have been found when considering separately phonological overlap and semantic overlap between familiar and novel words (e.g., Borovsky et al., 2016b; Fennel & Waxman, 2010). For instance, Borovsky et al. (2016b) found that a novel word belonging to a category dimension for which children knew many items (vs fewer items) was recognised with higher accuracy.

One might wonder whether the simultaneous combination of semantic and phonological information supports or hinders word learning, yet previous studies have studied these sources of information separately. Thus, the non-overlapping domain might have helped distinguish between novel label-referent associations. For example, in the study of Fennell and Waxman (2010), where children learned similar-sounding words (e.g., "din" and "bin"), children could have used the visual perceptual dissimilarity between the novel objects to discriminate between the referents associated with each novel word. Similarly, in the study of Borovsky et al. (2015b), when learning novel labels referring to food, such as "boba" and "mamey", participants could have used the phonological non-overlapping information contained in the labels to discriminate between the novel words.

When considering the combination of phonological and semantic overlap between novel label-referent associations, a study carried out by Twomey, Ranson & Horst (2014) found that children's word learning benefited from the presentation of multiple novel objects varying in one aspect (e.g., colour) more than when objects varied in two aspects (e.g., colour and shape). In the paper of Twomey and colleagues (2014), 2-year-old children were presented with a task where different objects were designed with a label (e.g., "doff"-"chem"). The authors manipulated whether the novel objects belonging to a category (e.g., "doff") were substantially different across multiple dimensions (e.g., shape and colour) or not (differed in only one dimension, e.g., colour). This study is an example of combining phonological and semantic overlap in novel label-referent associations, as the objects shared the same label (e.g., "doff") and shared perceptual features (e.g., shape or colour); thus, in this case, the items are phonologically and semantically related. The study's results indicate that young children learn novel label-referent associations if objects share some similarity but the within-object variability is not excessive. The research of Twomey et al. (2014), and Namy and Gentner (2002) is focused on categorisation learning (i.e., learning one label to refer to multiple objects), and this dissertation deals with the learning of word-object mappings (i.e., one label one object). However, categorisation learning studies are referred to here because they directly manipulate the phonological and semantic overlap between novel labels and referents.

Overall the papers reviewed here indicate that contrast in the phonological and semantic aspects of label-referent associations is important for the child to learn novel words. However, what remains unclear is how simultaneous phonological and semantic overlap in label-referent associations impacts novel word recognition, especially considering that previous research studied phonological overlap between novel labels (alone) or semantic overlap (alone), yet maintained the other aspect unrelated. Combining phonological and semantic domains is important as it helps to assess whether both sources of information generate an accumulated leveraging effect (from overlapping phonological and semantic aspects of words) thus boosting learning; or, on the contrary, if phono-semantic overlap results in difficulties for children to distinguish between concepts. Thus, the question here is which context is more suitable for word learning: one where novel labels refer to members of the same category that sound similar to each other (e.g., “peach” and “peanut”, which share the initial CV /piː/); or one where novel labels sound different from each other (e.g., “peach” and “mango”).

Therefore, in Study III (Chapter V), toddlers were presented with different learning conditions where phonological and semantic aspects of novel label-referent associations were manipulated to compare their impacts on novel word recognition. This study will allow us to know whether combined phonological and semantic overlap in the novel association is beneficial or detrimental for novel word recognition compared to phonological or semantic overlap alone.

I. D. Theoretical framework

Models of word recognition

Following the review of Weber & Scharenborg (2012), models of word recognition can be classified according to the specific aspect the model focuses on explaining, e.g., speech sound perception, word form recognition, or word meaning organisation in the lexicon.

Speech sound perception models, such as the LAFF model (Stevens, 2002) or ARTWORD (Grossberg & Myers, 2000), aim to explain how speech perception occurs. According to the model for lexical access based on acoustic landmarks and distinctive features or LAFF (Stevens, 2002), spoken words are accessed by assuming a mental representation of words formed by segments and features, and identifying the words through an analysis that exposes the segments in the word and the features that define the segments. Each segment consists of a bundle of distinctive binary features, and a change in one feature in one segment can generate a different word. The distinctive features are articulator-free or articulator-bound features. Articulator-*free* features specify the classes of articulatory actions that are not limited to specific articulations, and articulator-*bound* features specify which articulators are involved in producing the landmarks and how these articulators are positioned and shaped.

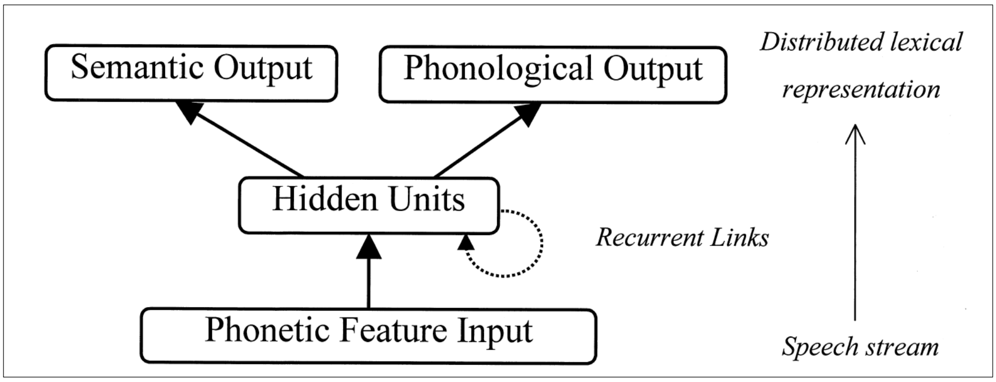
Word form models are mainly concerned with recognising word forms – i.e., the phono-lexical properties of labels – and overlook the role of meanings in that process. This group contains, for example, the Cohort Model (Marslen-Wilson & Welsh, 1978; Marslen-Wilson & Tyler, 1980), the TRACE model (McClelland & Elman, 1986) and Shortlist (Norris, 1994).

Semantic models describe how meanings are organised in the mental lexicon and are used to recognise words. This group comprises, among others, the Distributed Cohort Model (Gaskell & Marslen-Wilson, 1997), the Hierarchical Network Model (Collins & Quillian, 1969) and the Spreading Activation Model (Collins & Loftus, 1975). Within this group, the Distributed Cohort Model will be considered as the theoretical framework for this dissertation, as it attaches equal importance to phonological and semantic overlap in word recognition, and also because it has principles that can be extended to the accessing of recently acquired words.

The Distributed Cohort Model (Gaskell & Marslen-Wilson, 1997) postulates that the spreading of activation of the mental representation of word candidates to the spoken word occurs at the same level of representation – and not going through intermediate levels of representation as is proposed in other models such as TRACE or Cohort. According to this model, lexical representations combine semantic information (i.e., words' meanings) with abstract phonological information (i.e., phonemes) on a single mental level of representation. In the model, the input layer takes binary phonetic features from the input and passes them to a set of hidden units. Then the hidden units are connected to the output units, which represent the phonology and semantics of the words contained in the speech wave (see Figure 3).

Figure 3

Gaskell and Marslen-Wilson's (1997) Distributed Cohort Model of speech perception. Graph adapted from Gaskell and Marslen-Wilson (1999, p. 441).



Here, word recognition is achieved by directly mapping phonetic features onto abstract representations as speech unfolds. Thus, the semantic information is simultaneously retrieved as speech is perceived. That is, as the spoken signal unfolds, all candidates are activated concurrently, and their degree of activation changes over time. The right word candidate will be the one with the highest activation level, and those activation levels are determined through a competition process. Competition in this model is mediated by the number of other plausible candidates activated – the greater the number of other candidates, the lower the activation of each one.

The Distributed Cohort Model also provides a theoretical approach that considers the role of words' phonological and semantic features in word recognition. This model predicts that word beginnings with few completion possibilities will have higher semantic activation than words with many possibilities, as found in a priming study by Gaskell & Marslen-Wilson (2002). In addition, according to this model, infants and adults alike are capable of activating phonological and semantic features during word recognition, as shown in studies with infants where the recognition of words was modulated by preceding phonologically, semantically or phono-semantically similar words (Arias-Trejo & Plunkett, 2009, 2013; Mani et al., 2012; Mani & Plunkett, 2010a, 2011; Marslen-Wilson & Zwitserlood, 1989; Seidenberg et al., 1982; Slowiaczek & Hamburger, 1992).

Note that the models mentioned above were not designed to explain word recognition specifically in infancy. Although the underlying mechanisms of word recognition in adults and infants might follow the same fundamental principles (e.g., identification of similarities and differences), infancy is a period characterised by peculiarities that might impact how words are recognised, such as the u-shaped performance in different learning skills during this period (Carlucci & Case, 2013; Gershkoff-Stowe & Thelen, 2004; Rogers et al., 2004). Thus, the impact of phonological and semantic overlap between words on infants' performance in recognising and learning words might also follow this pattern. Similarly, word recognition might be different during infancy and in adulthood, given that children experience important neurodevelopmental changes such as synaptogenesis and later synaptic pruning (Dehaene-Lambertz & Spelke, 2015; Huttenlocher & Dabholkar, 1997; Huttenlocher, 1979). Thus, although lexical access in infancy is possible other related processes with word recognition (e.g., selective/sustain attention, inhibition of unrelated content) might not be fully developed yet.

All this considered, there is no reason why a model for adult speech recognition could not explain word recognition in infancy. However, given the constraints mentioned above, some caution should be taken when interpreting infants' data, as many processes are still in development.

Approaches and perspectives on word learning

Word learning in children can be explained by simple associative learning (e.g., Pavlov, 1927), in which children, based on exposure to word forms (e.g., "dog") accompanying a referent (e.g., the domestic animal), end up linking words with referents. Some perspectives consider that language is acquired by applying similar mechanisms to those involved in learning perceptual-motor skills (e.g., riding a bike, playing a musical instrument) (Chater & Christiansen, 2018; Chater, McCauley & Christiansen, 2016). Thus, the child learns language as a practical challenge from conversational interactions, and the inputs' linguistic structure plays an important role in word learning. Another perspective along the same lines, three time scales or slowing-down learning, proposes that our genetics prepare us to detect, decode, and attribute meanings to sounds, that is, to acquire language; while other processes – of general association learning – allow us to accumulate language experience in order to use that symbolic system accurately (Kucker et al., 2015; McMurray, 2016; McMurray et al., 2012).

Furthermore, the *leveraging learning* approach suggests that children's previous knowledge (e.g., knowing a large number of words to designate different animals) supports the acquisition of novel words based on the extraction of similarities between a novel lexical item and pre-existing concepts stored in the mental lexicon, in such a way that previous knowledge may enable the learner to infer many aspects of a novel word's meaning. For instance, Borovsky and collaborators' (2016a) paper showed that children's recognition of recently acquired words belonging to categories in which they knew a large number of words was facilitated in a preferential looking task.

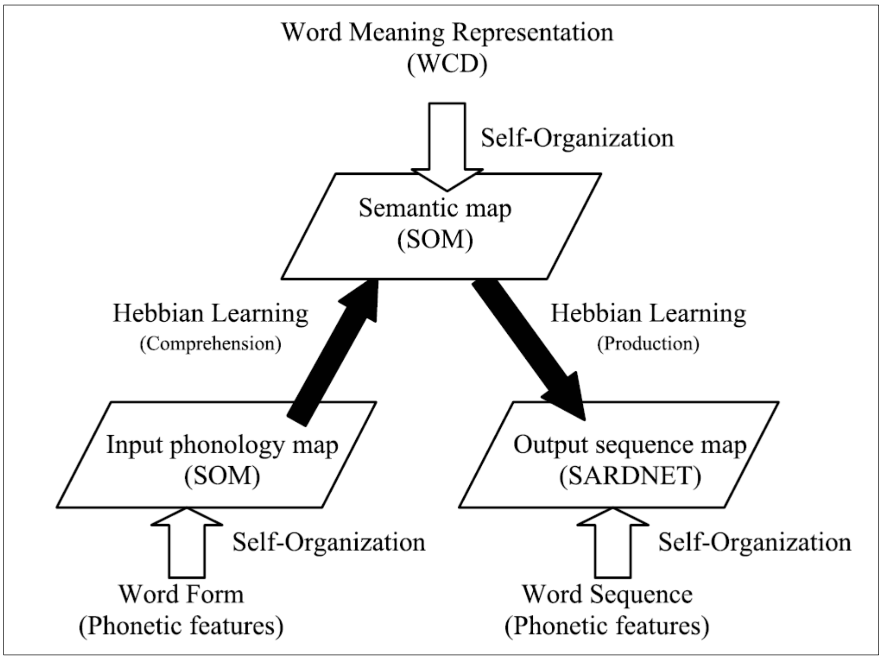
Models of word learning

Some models for word learning based on computational simulations consider explicitly the phonological (i.e., word form) and semantic (i.e., meaning) aspects of words on word learning, for example, DevLex (Li et al., 2004, 2007), and LEX (Regier, 2005).

DevLex and its revised version, DevLex-II (Li et al., 2004, 2007), have been proposed to simulate word learning in infancy (see Figure 4). This model is based on the self-organising feature of phonological and semantic maps connected via associative links trained by Hebbian learning (i.e., strengthened by the co-occurrence of words and objects). The phonological map includes word forms (i.e., strings of phonemes) which are activated from representations of phonetic features; and the semantic map contains semantic concepts (taken from language corpora) which are activated from a semantic input. The model is trained using word pairings to form representations on the respective phonological and semantic maps.

Figure 4

The DevLex-II model of lexical development. Each of the self-organising maps (SOM) takes input from the lexicon and organises phonology, semantics, and phonemic sequence information of the vocabulary, respectively. The maps are connected via associative links updated by Hebbian learning. Image taken from Li et al. (2007, p. 587).

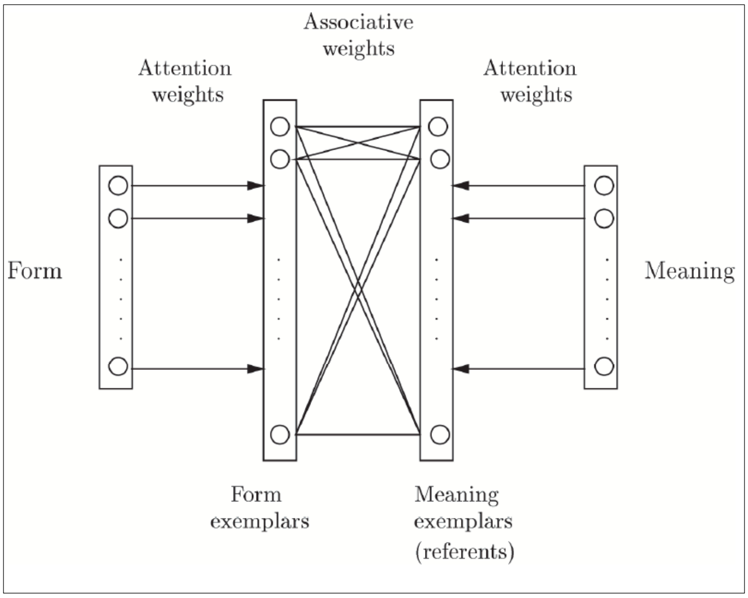


In DevLex (Li et al., 2004, 2007), word comprehension is simulated by presenting a word to the phonological map. The maximally activated unit or representation on the phonological map activates a semantic concept in the semantic map through the Hebbian links. The model simulates production with activation flowing from the semantic map towards the phonological map. This model successfully modelled some phenomena observed in infancy, such as the vocabulary spurt (and individual differences in its onset), early acquisition of high frequency and short length words, earlier word comprehension and later word production, and bilingual word learning. Although the phonological and semantic aspects of the words are included explicitly as fundamental self-organising structures that support word learning, this perspective does not provide specific predictions about how words’ phonological and semantic similarities interact with the formation of category meanings.

Finally, the LEX model (Reigier, 2005) proposes that the crucial mechanism involved in young children’s growing ability to learn new words is selective attention to relevant aspects of word forms (e.g., phonemes) and meaning, which reduces memory interference.

Figure 5

The LEX model (Regier, 2005). Image adapted from Regier, 2005, p. 828.



The model architecture is depicted in Figure 5. It is a bidirectional model where, given a word form, the model produces a probability distribution over associated referents (i.e., exemplars of meaning); and vice versa, given a referent the model produces a probability distribution over associated exemplars of form. These associations are mediated by a single set of associative links, connecting the two hidden layers of the model. The hidden layers contain nodes that represent already encountered exemplars that have been stored (one for form exemplars, and one for meaning exemplars or referents). Form exemplar nodes and meaning exemplar nodes are associated one to one, through associative weights. Additionally, there are also weights encoding selective attention to each dimension of form (e.g., for phonetic features such as voicing or pitch that helps to discriminate among minimally different words such as “pat” and “bat”) and each significant dimension of meaning (e.g., shape or colour, which helps to differentiate referents belonging to the same category). The weights encoding selective attention stretch and compress the word forms with meanings in clusters. Flexibility in clustering word forms and meanings based on selective attention reduces memory interference, because attention is allocated to significant dimensions and away from insignificant ones. Thus, when a novel word or referent is presented, no other exemplars will be near (in the form or meaning space), because the novel word by definition differs from other words along significant dimensions.

The LEX model has some predictions concerned with similarities in word form and meaning. As mentioned in Regier (2005, p. 848), “Because weight updates are affected by both form and meaning, two words that are similar in form and have similar referents should be maximally difficult to learn and keep distinct in memory, two words that are similar in only one or the other should be of intermediate difficulty, and two words that are dissimilar in both form and referent should be relatively easily learned.” Therefore, given the specificity of these predictions, the LEX model will be considered the theoretical framework for the results of Study III.

Chapter II. Summary of the empirical section

This chapter summarises, in essence, the three empirical studies presented in the current dissertation. The studies will be detailed in Chapters III to V. The first study consists of a longitudinal investigation of the differential roles of vocabulary size and age on the phonological and on the semantic priming effects in toddlers. The study investigates a cohort of toddlers (German monolinguals) as they grow from 18 to 24 months (Avila-Varela, Arias-Trejo & Mani, 2021). The second study follows, motivated by the need to clarify some aspects of the results of Study I. It compares how the combined phonological-semantic overlap impacts word recognition compared to the case in which only phonological overlap is present (Avila-Varela, Jones & Mani, *in preparation*). The experiment for Study II was conducted at the Nottingham Trent University in collaboration with Prof. Gary Jones and studied a cohort of toddlers (English monolinguals) aged 17 - 27 months, average 21.7 months. Finally, Study III dives into the question of how words similarities impacts on the learning process and how this is reflected in novel word recognition in toddlers (German monolinguals, 20 - 24 months, average 21.8). Therefore, it manipulates the phonological and the semantic aspects of novel words to learn and assess their impact on novel word recognition (Avila-Varela, Hartmann & Mani, *in preparation*).

II. A. Study I: Longitudinal word recognition experiment

Studies of word recognition in adults have long reported a facilitator effect when similar-sounding words or when words with shared meanings are presented in quick succession, one after the other (Slowiaczek & Hamburger, 1992; Meyer & Schvaneveldt, 1971). In the recent years attention has turned to the study of phonological and semantic priming in children and toddlers finding that at 18 months children show phonological facilitator effects but not semantic priming effects; then at 24 months children show facilitator recognition of semantically related words while starting to display phonological interference effects (Mani & Plunkett, 2010; Styles & Plunkett, 2009; 2013). However, several questions remain open given the fact that early toddlerhood is a developmental period characterized by an accelerated rate in word and conceptual learning (Fenson et al., 1994; Frank, et al., 2021 Ganger & Brent, 2004). Early research has reported the influence of children vocabulary size on performance on language processing tasks (Fernald et al., 2001, Fernald & Marchman, 2012, Borovsky et al., 2012, Mani & Huettig, 2012; Junge et al., 2012, Friedrich & Friederici, 2006; Borgström et al. 2015, Lany et al., 2018, Borovsky & Peters, 2019) and priming tasks (Rämä et al., 2013; Mani & Plunkett, 2011). However, most research on phonological and semantic priming effects in infancy comprises cross-sectional studies in which different participants were sampled at different ages, thus dissipating the possible contribution of each participants' vocabulary size on word recognition at a critical age in which vocabulary is growing rapidly.

Motivated by this gap in the literature, Study I proposed the first longitudinal study (testing the same sample of participants as they grow) that would allow controlling for the individual subject variability in vocabulary size over age; thus, helping to disentangle the roles of age and vocabulary size on the phonological and on the semantic priming effects for word recognition. In particular, the study comprised a cohort of German monolingual infants who were tested three times: at 18, 21 and 24 months of age. An intermodal preferential looking task adapted to a priming paradigm was combined with eye-tracking to measure the influence of phonologically and semantically related/unrelated primes on target recognition.

The results of Study I show that the phonological priming effects are predicted by the current vocabulary size of the participants, even after controlling for their age. In contrast, semantic priming effects were not predicted by vocabulary size or age. In addition, early phonological priming effects predicted later semantic priming effects, and vice-versa, early semantic priming effects predicted later phonological priming effects. This observation indicates that children's early phonological facilitation predicted their late semantic interference at 24-months, thus showing a relationship between early and late sensitivity to similarities between words.

II. B. Study II: Effects of combined phonological and semantic overlap

Study I found that phonological interference was modulated by children current vocabulary size, a result that is congruent with past studies finding phonological interference effects in 24- but not in 18-month-old toddlers turn that has been proposed to be linked with growing vocabulary associated with age (Mani & Plunkett, 2011). However, in Study I, we also identified semantic interference to be present at all three ages (18, 21 and 24 months) while past studies had reported semantic facilitation at 21 and 24 months (Arias-Trejo & Plunkett, 2009, 2013).

Therefore, Study II was designed as a consequence of these results from Study I, with the goal in mind to clarify whether phonological interference effects could be reduced by adding semantic overlap.

Along these lines, previous research implementing a mediated priming paradigm shows that children activate phono-to-semantically related words (Mani et al., 2012; Altvater-Mackensen & Mani, 2013a) and semantic-to-semantic related words (Angulo-Chavira & Arias-Trejo, 2021). Later, at 30 months of age, it was found that the activation also flows from semantic to phonological links (Angulo-Chavira & Arias-Trejo, 2018). However, the mediated priming paradigm studies the activation flow of related words in a two-steps activation process. First, related words to an initial word (i.e., the prime) are activated, from which an intended mediator word is pre-activated, and secondly, then given a relationship between the mediator word and the target (e.g., shared phonemes or meaning) target recognition is facilitated.

In addition, it is essential to note that in the study of single links (either phonological or semantic alone), additive priming paradigms were implemented (e.g., Mani & Plunkett, 2011; Arias-Trejo & Plunkett, 2011). In the additive priming paradigm, the recognition of the target is modulated by the overt relationship with the prime. Thus, applying the additive priming paradigm allows the study of the impact of words relationships at the same phase/stage of processing, without the need for the implicit activation of a mediator stimulus on an additional processing step.

Study II (Avila-Varela, Jones & Mani, *in preparation*) aimed at comparing how the combined phonological and semantic overlap impact recognition in contrast to the situations in which only one of the two sources of overlap – phonological or semantic – is presented alone. An additive priming paradigm was utilised to study the combined sources of overlap effects at the same stage of processing. In particular, the study examined whether adding semantic information to phonologically related pairs of words would reduce the phonological interference previously acknowledged in 2-year-old children (Mani & Plunkett, 2011). We tested phonological and phono-semantic priming effects in monolingual British children at 21 months. We used the intermodal preferential looking task adapted to a priming paradigm combined with eye-tracking to measure the influence of phonologically and phono-semantically related/unrelated primes on familiar target recognition. The experiments for Study II were carried out in the lab of Prof. Gary Jones at the Nottingham Trent University during a collaborative research visit.

Analysis of total looking times by means of generalised linear models was applied to the recorded eye-tracking trajectories to assess the difference in total target looking time across conditions and lexical links. Also, growth curve analysis examining the changes in infants' looking behaviour trajectories during target recognition was assessed. The results showed that, in general terms, target recognition was higher in the phono-semantically trials (related and unrelated) than in the phonological trials (related and unrelated). In addition, when considering the changes on target fixation curves, evidence of phonological and phono-semantic priming effects was found, with an early advantage in target looking in the unrelated conditions, indicating phonological and phono-semantic interference effects.

These results align with the Distributed Cohort Model (Gaskell & Marslen-Wilson, 1997), which considers that both the form and the meaning of words contribute to word recognition as both sources of information – in combination – reduce the activation of related yet not intended words. Thus, in Study II, the addition of semantic information to phonologically related words narrowed down the number of competing candidates activated based on the phonological similarity.

II. C. Study III: Influence of words overlap on novel word recognition

The main focus of Studies I and II, as much of the past literature, was to discriminate the sources of facilitation and interference in word recognition as triggered by phonological or semantic (or both) similarities on word recognition. However, as stated in the motivation for Study I, toddlers aged 18- to 24-months undergo a developmental period of accelerated learning: understanding of the surrounding world and developing the linguistic skills to describe and interpret it. Study I paid attention to the influence that the growing lexicon in toddlers affect their word recognition capabilities, thus assuming a "passive" learning framework. That is, toddlers were tested longitudinally from 18 to 24 months while their learning of new vocabulary happened uncontrolled, during their daily life outside of the experimental environment.

In order to gain understanding of the influence of words overlap on word learning, in Study III we manipulated the amount of overlap between novel words to learn. Therefore, in Study III 2-year-old children were taught two novel words that overlapped only phonologically, only semantically, phono-semantically, and were unrelated.

Previous evidence shows that children learn novel words that sound similar or belong to the same category to familiar words (Altvater-Mackensen & Mani, 2013b, Fourtassi et al., 2021, Newman et al., 2009; Borovsky et al., 2016c). In addition, further evidence supports that children can learn novel words that share form and meaning (Twomey et al., 2014; Namy & Gentner, 2002). Nevertheless, more research about the impact of the novel words overlapping simultaneously in form and meaning is required, given that such combined overlap might impair the discrimination among the novel words to acquire. Also, testing different learning scenarios in which the novel words overlap phonologically, semantically, or both, or are unrelated; can provide additional evidence on the more appropriate context for word learning in young children.

Following this intuition, Study III (Avila-Varela, Hartmann & Mani, *in preparation*) proposed to compare the recognition of recently taught words in toddlers under four distinguished learning conditions:

1. **Phonologically related**, where the two novel labels shared the initial syllable (e.g. /simi/ and /sinqa/); and their referents belonged to different categories (e.g. "food" and "musical instrument").
2. **Semantically related**, where referents belonged to the same category (e.g. "food"); and labels were phonologically dissimilar (e.g. /simi/ and /alku/).
3. **Phono-semantically related**, where labels shared the initial syllable (e.g. /simi/ and /sinqa/) and referents belonged to the same category (e.g. "food"); and
4. **Unrelated**, where labels were phonologically dissimilar (e.g. /simi/ and /alku/), and their referents belonged to different categories (e.g. "food" and "musical instrument").

In this study we considered the fixations towards the novel target as the measure of word learning. Total-looking-time and time-course analyses were carried out from the recorded fixation trajectories.

The results showed that while total-looking-time did not discriminate significant differences across conditions, the results from the time-course analyses identified a better target recognition of novel words in the phonologically and in the semantically related conditions (cases A and B) than in the combined phono-semantically related condition (C). Also, as expected, the results confirmed that novel word recognition was worst in condition (D) when the novel words were unrelated.

Chapter III. Avila-Varela, Arias-Trejo & Mani (2021)

Avila-Varela, D. S., Arias-Trejo, N., & Mani, N. (2021). A longitudinal study of the role of vocabulary size in priming effects in early childhood. *Journal of Experimental Child Psychology*, *205*, 105071. https://doi.org/10.1016/j.jecp.2020.105071

Note: A difference with the published text, the numbering of the tables and figures has been modified to align with the general thesis text, and the references have been moved to the comprehensive list of references.

A longitudinal study of the role of vocabulary size on priming effects in early childhood

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III. Abstract

Studies on lexical development in young children often suggest that the organisation of the early lexicon may vary with age and increasing vocabulary size. In the current study, we explicitly examine this suggestion in further detail using a longitudinal study of the development of phonological and semantic priming effects in the same group of toddlers at three different ages. In particular, our longitudinal design allows us to disentangle effects of increasing age and vocabulary size on priming and the extent to which vocabulary size may predict later priming effects. We tested phonological and semantic priming effects in monolingual German infants at 18-, 21- and 24-month-olds. We used the intermodal preferential looking paradigm combined with eye tracking to measure the influence of phonologically and semantic related/unrelated primes on target recognition. We found that phonological priming effects were predicted by participants' current vocabulary size, even after controlling for participants' age and participants' early vocabulary size. Semantic priming effects were, in contrast, not predicted by vocabulary size. Finally, we also found a relationship between early phonological priming effects and later semantic priming effects, as well as between early semantic priming effects and later phonological priming effects, potentially suggesting (limited) consistency in lexical structure across development. Taken together, these results highlight the important role of vocabulary size in the development of priming effects in early childhood.

Keywords: infant, eye-tracking, longitudinal study, vocabulary, word recognition.

A Longitudinal Study of the Role of Vocabulary Size on Priming Effects in Early Childhood

Language comprehension begins early in life. By around 12-months of age, most children are able to understand and produce a dozen or more words, with this number increasing across the second year of life to more than 400 words (Bates & Goldman, 1997; Fenson et al., 1994). Furthermore, parental reports suggest that there is an acceleration in vocabulary growth from around 16- to 20-months of life, followed by a second burst from 24- to 30-months of age (Bates & Goldman, 1997; Fenson et. al, 1994). This expansion in vocabulary might necessitate that children detect similarities among words in their vocabulary and organise their lexicons along repeatedly reoccurring dimensions to better store the words they acquire. Indeed, studies suggest that children detect phonological (Mani & Plunkett, 2010, 2011), and semantic similarities between words (Arias-Trejo & Plunkett, 2009, 2013; Mani, Durrant & Floccia, 2012; Altvater-Mackensen & Mani, 2013), as well as similarities based on visuo-perceptual properties of word referents (Arias-Trejo & Plunkett, 2010; Johnson, McQueen & Huettig, 2011; Mani, Johnson, McQueen & Huettig, 2013; Bobb, Huettig & Mani, 2016) from early on. Thus, words appear to be organised according to their phonological, semantic and visuo-perceptual properties in the mental lexicon (see Mani & Borovsky, 2017).

These studies also highlight developmental differences in such organisation with differences in children's sensitivity to phonological or semantic overlap at different ages (outlined in detail below). However, most studies to date on priming effects in early word recognition are cross-sectional. Therefore, the results of when such priming effects begin to appear in development and the factors that influence them may merely reflect the cohort of participants studied at each unique point in time and not a general developmental trend. While a number of studies suggest that children's age and/or vocabulary size may influence the priming effects reported at different ages, the cross-sectional nature of such studies do not allow conclusions about the factors influencing the onset of these effects across development.

Against this background, we adopt a longitudinal approach to examining the development of phonological and semantic priming effects across the latter half of the second year of life. The longitudinal approach will allow us to better disentangle the factors that lead to the finding of a priming effect across development, with particular regard to the relative influence of increasing age and increasing vocabulary knowledge on priming. In other words, we ask whether chronological age or vocabulary development better predicts the priming effects reported in the studies thus far. Furthermore, such a longitudinal stance also allows us to better examine the relationship between priming and vocabulary size, i.e., we ask whether participants' early receptive vocabularies or their current receptive vocabulary size better predicts the priming effects reported later in life, with a view to examining the causal role of receptive vocabulary size in the development of priming effects. Relatedly, we also examine the relationship between the priming effects found early in development to the effects found at later testing ages to examine the consistency of these effects and the extent to which they may influence one another.

Classically, studies examining the organisation of words in the early lexicon have used a priming adaptation of the intermodal preferential looking paradigm (IPL). In the original IPL paradigm (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987), two pictures are presented side-by-side on-screen (e.g., an *apple* and a *table*), while an audio recording names one of the displayed objects, (e.g., Oh! Look at the *apple*!). In the priming adaptation of this task, the images and the target labels are preceded by a prime stimulus, which could be either a label (e.g., Styles, Arias-Trejo,

& Plunkett, 2008) or an image that overlaps in certain features with the target (e.g., Mani & Plunkett, 2010). Typically, the prior presentation of a related prime leads to either improvement or delay in target recognition (relative to an unrelated prime) depending on the type of the relationship between the prime and the target. Facilitation effects on word recognition are indexed by shorter response times to fixate the target or increased fixations to the target when the target label is preceded by a related prime relative to an unrelated prime (Meyer, & Schvaneveldt, 1971). Interference effects on word recognition are either indexed by longer response times to fixate the target or reduced fixations to the target when the target label is preceded by a related prime relative to an unrelated prime. This priming adaptation has recently been combined with automated eye tracking (see Delle-Luche, Durrant, Poltrock, & Floccia, 2015; Golinkoff, Ma, Song, & Hirsh-Pasek, 2013, for methodological reviews) and event-related potential data (e.g., Rämä, Sirri, & Goyet, 2018; Rämä, Sirri, & Serres, 2013; Torkildsen, Syversen, Moen, Simonsen, & Lindgren, 2007).

Phonological Priming Effects in Early Childhood

The study of phonological links in the early lexicon is typically undertaken by presenting infants with pairs of words, which overlap in some phonological features, and examining the time course and pattern of their recognition of the related words. These studies show that 18-month-olds recognize a target better (e.g., *dog*) when it is preceded by a phonologically related prime (e.g., *door*) compared to a phonologically unrelated word (e.g., *boat*, Mani & Plunkett, 2010). However, this initial facilitation effect morphs into an interference effect at twenty-four months of age (Mani & Plunkett, 2011), such that two-year-olds look longer to the target (e.g., *dog*), when it is preceded by a phonologically unrelated word (e.g., *boat*) compared to a phonologically related word (e.g., *door*). The shift from phonological priming facilitation to interference has been attributed to the increasing number of phonologically similar sounding words known by older children. This suggestion is supported by the finding that phonological interference effects are mediated by the cohort size of prime and target words used (Mani & Plunkett, 2008, 2011).

The authors explain this result by suggesting, as proposed in models of word recognition (Marslen-Wilson & Welsh, 1978; Gaskell & Marlsen-Wilson, 2002), that other similar sounding words are retrieved during word recognition. When the number of alternative phonologically overlapping candidates exceeds a critical mass, their activation interferes with target recognition. They further explain the contrast between the findings at eighteen and twenty-four months of age with a switch from phonologically to lexically driven effects with increasing vocabulary size (Mani & Borovsky, 2017). Early in life, with fewer words in the lexicon, hearing similar words may not trigger similar inhibitory lexical level effects and recognition may be eased by the phonological overlap between words. The larger vocabularies later in development may lead to greater competition between words and the introduction of inhibitory links between words in more mature lexicons (see also Mayor & Plunkett, 2014).

Taken together, the reviewed literature highlights a developmental trend where experience with language plays an important role in the development of phonological links between words, with a potential sensitive period between eighteen and twenty-four months of age (Mani & Borovsky, 2017; Mayor & Plunkett, 2014), where the direction of reported effects may be vulnerable to either increasing age or vocabulary knowledge. Against this background, using a longitudinal design, we re-examine the development of phonological links between words during this period of eighteen and twenty-four months of age.

Semantic Priming Effects in Early Childhood

The study of the semantic organization in the early lexicon is typically undertaken by presenting children with words related in meaning and examining the recognition of a given word when it was preceded by a semantically related prime compared to a semantically unrelated prime. Studies adapting the IPL paradigm with semantic priming have examined the formation of taxonomic (e.g., *dog-chicken*) and associative links between words in the early lexicon (e.g., *dog-bone*) as well as combined taxonomic and associative links between words (e.g., *dog-cat*).

Some work suggests that, at eighteen months, toddlers do not display sensitivity to either associative or taxonomic links between words (Arias-Trejo & Plunkett, 2009; see also Styles & Plunkett, 2009, 2011). Later on, twenty-one-month-olds demonstrate a semantic priming effect, looking longer at a labelled target image when it was preceded by the auditory presentation of a taxonomically *and* associatively related prime (Arias-Trejo & Plunkett, 2009), relative to an unrelated auditory prime. However, recent studies applying simplified versions of such priming tasks report earlier semantic priming effects. For instance, Bergelson and Aslin (2017) presented 12- to 14-month-old infants with pairs of pictures (e.g., *foot* and *juice*) as they named a matching word (e.g., *foot*) or an absent but semantically related word (e.g., *sock*). Here, while younger children fixated the target -e.g., *foot*- equally in matching and semantically related conditions, older children fixated the referent more in the matching condition relative to the semantically related condition. The authors interpret these findings as highlighting the fine-tuning of early semantic representations during the second year of life.

Other methods, such as the Head Turn Preference Procedure (HPP), have also been used as an index of sensitivity to the semantic relatedness of words and report finding semantic priming effects at both 18- (Delle Luche, Durrant, Floccia & Plunkett, 2014) and 24-months of age (Willits, Wojcik, Seidenberg & Saffran, 2013). In the HPP, children are presented with lists of words that could be either semantically related (e.g., *dog, cat, cow*) or semantic unrelated (e.g., *dog, car, flower*), with differences in listening times to lists of related and unrelated words being interpreted as sensitivity to the semantic relationship between words. The authors explain the difference in results between the IPL and the HPP studies with recourse to the paradigm used, where the requirement to simultaneously process both visual and auditory information in the IPL paradigm entails a higher cognitive load relative to the HPP method, overriding any potential semantic priming effects (Delle Luche et al., 2014).

Similar to the results reported by Arias-Trejo & Plunkett (2013) and the results on phonological priming (Mani and Plunkett, 2010, 2011), these findings describe a developmental trend where children, typically by the end of their second year of life, are sensitive to the semantic links between words. The developing sensitivity to these links may, further, be related to the vocabulary size of the children rather than merely chronological age, as we discuss next.

Variation in Priming Effects Across Early Childhood

The priming effects reported at the different ages tested are typically explained with recourse to either the demands placed on the child and, necessarily, then, the cognitive abilities of the child or the linguistic development of the child. With regards to children’s cognitive development, despite children´s notable proficiency in building, storing and using words properly, these are not trivial tasks. To succeed at this task, children must simultaneously coordinate multiple cognitive skills (phonological discrimination, visual perception, motor control, processing memory, among others), and it may very well be possible that chronological age as an index of children’s cognitive abilities may explain the finding of priming effects at the different ages tested.

At the same time, a number of studies on word recognition in infancy have found evidence of an influence of children’s vocabulary size on their sensitivity to the phonological and semantic relatedness of words. Chow, Aimola-Davies & Plunkett (2017) report that individual differences in vocabulary size predicted better access to phonological and semantic information than participant's age at testing. Specifically, they found that 24- to 30-month-olds with larger receptive vocabularies, were more likely to fixate a phonological distractor than children with smaller vocabularies. With a different sample (from twenty-five to thirty months of age), participants’ expressive vocabulary size predicted toddlers’ preference to fixate a thematically related distractor (Chow et al., 2017). In an electrophysiological task, Rämä et al. (2013) presented 18- and 24-month-olds with an acoustic semantic priming task, where they heard pairs of words which were either taxonomically related or unrelated and report an N400-like priming effect only in 24-month-olds and in 18-month-olds with higher expressive vocabulary. These results suggest that children´s receptive and expressive vocabulary sizes may modulate their sensitivity to phonological and semantic links between words.

Similarly, Mani & Plunkett (2011) report that the number of words known to children that overlapped with the target significantly impacted children’s target recognition, suggesting again that children’s receptive vocabulary may modulate the phonological priming effects found. Meanwhile, in a study examining children’s use of thematic information to predict upcoming language input, Mani & Huettig (2012) found that the sensitivity to the thematic links between verbs and their arguments was modulated by the expressive vocabulary size of the children tested.

In a longitudinal study, Borgström, Torkildsen and Lindgren (2015) find that children’s sensitivity to shape similarity between objects at twenty months of age predicts their later vocabulary development at 24-months of age. These results suggest that differences in sensitivity to shape similarity between words may be related to later lexical development. Similarly, Friedrich and Friederici (2006) found that children with larger vocabulary size at thirty months of age, when they were nineteen months, already displayed an N400 potential in conditions of lexical priming (e.g., naming *dog* while displaying the picture of a *dog*). Both these studies highlight potential directional effects of vocabulary size and the priming effects reported with larger vocabulary size early in development predicting the size of the priming effect later in life.

Taken together, the studies reviewed suggest that individual variation in vocabulary size may predict sensitivity to phonological and semantic links between words in children, with earlier sensitivity to such links in children with larger vocabularies. These studies also highlight the possibility that phonological and semantic priming may be differentially impacted by children’s receptive and expressive vocabulary size.

Against this background, the current study aims to provide a longitudinal view of the development of phonological and semantic lexical links in monolingual infants and to clarify the role of participants' receptive vocabulary size in the development of such links between words in the early lexicon. The use of a longitudinal design, where we test the same cohort of participants at three different ages, will allow us to better pinpoint the role of infants´ vocabulary size on the development of phonological and semantic lexical links. At the same time, it will provide an opportunity to compare the developmental trends of phonological and semantic effects across this period and examine whether and how phonological and semantic links influence each other. This will be of key importance to previous studies and models of lexical organisation (Huettig & McQueen, 2007; Chow, et al., 2017; Gaskell & Marslen-Wilson, 2002), highlighting how the semantic and phonological properties of words interact during the development of lexical links between words to support word recognition.

The Current Study

In the current study, participants took part in a priming task at three time points, at eighteen, twenty-one and twenty-four months of age. We focused on these ages for the following reasons: First an overwhelming number of priming studies in the literature have investigated children between these ages, thereby allowing us to compare our results to this literature. Second, children substantially increase their vocabulary during this period allowing us to examine how this rapid vocabulary development influences the reported priming effects (Bates & Goldman, 1997; Fenson et al. 1994; Szagun, Stumper & Schramm, 2009). In each session, participants were exposed to two phonological and semantic conditions each (related and unrelated), such that each participant saw four combinations of *prime-target* pairs, namely, phonologically related, phonologically unrelated, semantically related and semantically unrelated.

The main focus of the current study is to examine the development of phonological and semantic priming effects across the three time-points tested, with a particular focus on the role of receptive vocabulary size and age at testing on the development of these effects. Additional analyses will then examine the extent to which vocabulary size at the time of test or earlier vocabulary differences drive the priming effects reported. This will attempt to disentangle the role of vocabulary size in predicting later development of such priming effects (c.f., Borgström et al., 2015, Friedrich & Friderici, 2006). Finally, exploratory analyses will examine the consistency of these priming effects by looking at whether early priming effects predict the development and strength of later priming effects both within and across priming conditions, i.e., whether early priming effects predict later phonological priming effects or later semantic priming effects.

Given the studies reviewed above, we expected to find early facilitation effects in phonological priming (at eighteen months) that morph to interference effects at the later ages (twenty-one to twenty-four months) tested, and the development of semantic priming effects only towards these later ages (Mani and Plunkett, 2010, 2011; Arias-Trejo & Plunkett, 2009, 2013). Furthermore, we also predicted effects of receptive vocabulary size on word recognition with potentially stronger effects of semantic and phonological priming in children with larger vocabularies. Of interest is also the extent to which the finding of priming effects at the earlier ages modulates the priming effect at later ages, both within and across relatedness conditions, i.e., phonologically and semantically related trials.

III. Method

Participants

Data from 38 typically developing children (20 females and 18 males) from German-speaking families were included in the analysis. In Table 1 we describe participants' age in each session. We ensured an average gap of 3.23 months (range = 2.07-4.83) between the first and second session as well as between the second and third session (range= 1.97-4.26).

Table 1

Participants' age (in months) per session.

Session	Average age	Range
First	18.19	17.73-18.93
Second	21.42	20.53-22.73
Third	24.65	23.90-25.23

All participants were recruited from the laboratory database. Of the families included, 89.64% were families where one or both caregivers were in full or partial employment and 92.31% were families where one of both caregivers had completed a college degree. This sample can reasonably be considered a high Socio-Economic-Status (SES) sample. Thus, caution should be taken when generalizing the conclusions of this work to other SES samples (see Fernald, Marchman and Weisleder, 2012; and Levine et al., 2020).

An additional 28 infants were excluded from further analysis (see Table 2 for the detail of the exclusion criteria applied). High dropout numbers are common in longitudinal studies, e.g., in Borgström, et al. (2015), from 77 participants tested at 20-months, 52 returned at 24-months and only 23 participants fulfilled the inclusion criteria at both ages.

Table 2

Number of participants excluded from analysis.

Number of Participants	Exclusion Criteria
13	missing a follow up session
2	missing follow up information (here, vocabulary inventory)
1	auditory problems reported on the first session
3	bilingual exposure at home
1	technical problems
8	other exclusion criteria (see subsection “Exclusion criteria”)

Stimuli

Ninety-six nouns familiar to children from eighteen to twenty-four months of age according to the Fragebogen zur Frühkindlichen Sprachentwicklung (FRAKIS; Szagun, et al., 2009) were selected as stimuli. With those words, we formed 32 triplets (prime, target and distractor), each of which constituted the stimulus for a single trial. The pictures used as target and distractor were equally likely to be familiar to the child at the ages tested (see Table 3).

Table 3

Participants´ familiarity with the labels used as target and distractors.

	Familiarity	
Session	Target label	Distractor label
18-months	79.32%	62.47%
21-months	94.00%	90.79%
24-months	97.67%	96.20%

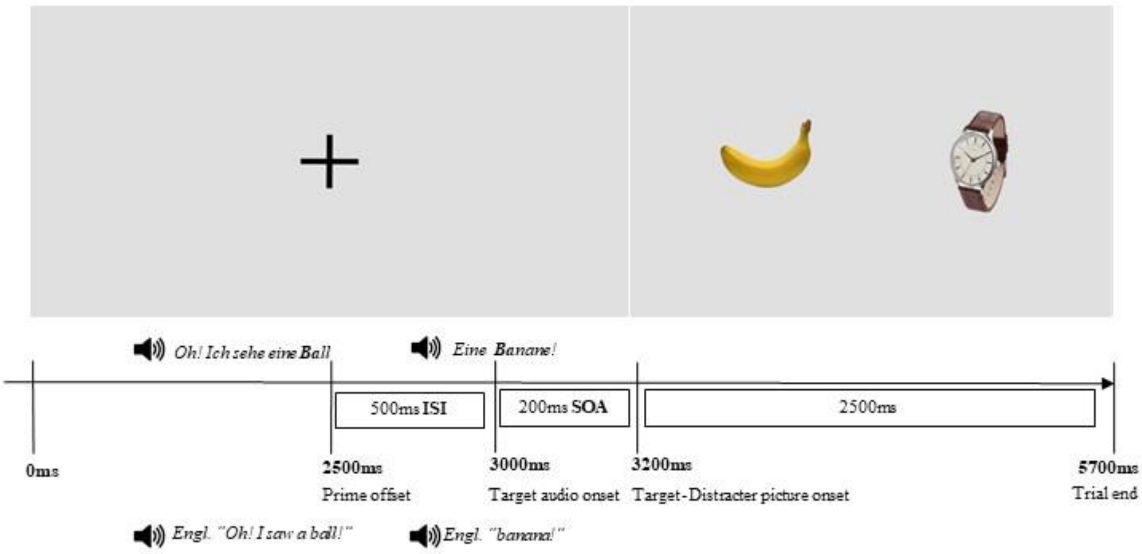
Auditory stimuli were recorded by a native German female speaker using infant-directed speech. Prime words with their indefinite article were recorded in isolation and then inserted into one of three carrier phrases (i.e., “*Hey! Ich habe ein/e [prime]!*”, “*Wow! Ich sehe ein/e [prime]!*”, or “*Huhh! Ich kaufe ein/e [prime]!*”, Engl. “Wow! I have a [prime]!”, “Hey! I see a [prime]!” or “Huhh! I buy a [prime]!”) where the word used as prime occurred in the final position. Target words were recorded in isolation and then inserted into the trial following the prime word in each condition. Auditory stimuli were subsequently processed using GoldWave software (St. John’s, Newfoundland and Labrador, Canada). First, the sentences and isolated tokens were spliced from the full recording. Next, background noises, head and tail clicks were removed manually. Finally, the targets and prime sentences were spliced together to form a single audio file.

Prototypical images depicting the target and distractor were used visual stimuli. The pictures were chosen from public libraries available online and were displayed against a grey background. We presented different pictures in each session to ensure that children did not see the same images across sessions. Images were edited using GNU Image Manipulation Program. Finally, the auditory and visual stimuli were combined using Video moviemaker to create separate videos for each trial presented.

Trial Structure

Trial onset was manually controlled by the experimenter once the child fixated a green fixation cross at the centre of the screen. The trial began with the presentation of the carrier phrase containing the prime stimulus combined with the display of a centrally located black fixation cross. Importantly, the prime was presented in absence of any visual stimuli aside from the fixation cross. The prime label offset was timed at 2500ms from the trial onset. The target label was presented at 3000ms into the trial, with an interstimulus interval of 500ms between target and prime. The target and distracter pictures followed 3200ms into trial and remained on screen for 2500ms. Thus, the duration of each trial was 5700ms (see Figure 6).

Figure 6 Trial stimuli sequence presentation.



Trial Presentation and Counterbalancing

In each session, participants were presented with phonologically related (*Phon-Rel*), phonologically unrelated (*Phon-Unrel*), semantically related (*Sem-Rel*) and semantically unrelated (*Sem-Unrel*) trials. Due to the limited number of words familiar to children at the tested ages, we repeated a subset of words used across sessions. At the first session, we presented 24 trials (six trials per lexical type '*Phonological*' or '*Semantic*' and condition *'Related'* or *'Unrelated'*). In subsequent sessions, we presented 32 trials (eight trials per type and condition). We followed a within-subjects design, where trials appeared in a pseudorandom order, with no more than three consecutive trials of the same type in succession. The order of trial presentation differed across sessions. See Appendix A for the word pairs used at the first session and Appendix B for the words used at the second and third sessions.

In *Phon-Rel* trials, primes and targets overlapped in the initial phonemes, e.g., CV[1] *Bus* [prime] – *Buch* [target] (Engl. bus – book) (see Ramos-Sanchez & Arias-Trejo, 2018 for a similar approach). In *Sem-Rel* primes and targets were from the same superordinate category but were not strongly associated with one another according to the Noun Associations for German database (Melinger & Weber, 2006), e.g., *Affe* [prime] – *Ente* [target] (Engl. monkey – duck). Targets and primes in the *Phon-Rel* trials belonged to different superordinate categories, were associatively unrelated and were visually dissimilar. Targets and primes in *Sem-Rel* trials were phonologically unrelated and did not overlap along visual dimensions either.

We used the same prime and target labels in the related and unrelated pairs, ensuring that in the unrelated conditions each target was paired with a prime, which did not overlap in their initial phonemes and belonged to different superordinate categories. For example, *Puppe* [unrelated prime] – *Buch* [target] in the *Pho-Unrel* condition (Engl., doll – book); and *Löffel*[unrelated prime] – *Ente* [target] (Engl. spoon – duck) for the *Sem-Unrel* condition.

The words used appear uniquely in one of the two relationships studied here, that is, either in the phonological condition (*Phon-Rel* or *Phon-Unrel*) or in the semantic condition (*Sem-Rel* or *Sem-Unrel*). Across sessions and participants, words were counterbalanced such that primes and target-distractor pairs appeared equally often in the related and unrelated conditions (within phonological or semantic lexical links). We ensured that prime-target pairs were not repeated at subsequent sessions, thus if a target was presented in a related trial in one session, it would be presented in an unrelated trial in the next session, and vice versa. The side of presentation of the target picture side (left, right) also was counterbalanced across infants.

Since nouns in German have obligatory grammatical gender (neutral, feminine or masculine) and previous findings show gender based priming effects (Bobb & Mani, 2013), we ensured that prime and target did not uniquely overlap in gender. This was not always possible with the distractor.[2]

Procedure

Each participant attended one session every three months, at eighteen, twenty-one and twenty-four months of age. Prior to each visit, caregivers filled out a subset of the FRAKIS (Fragebogen zur fruhkindlichen Entwicklung) a German communicative inventory to provide us an estimate of participants' receptive and productive vocabulary size (Szagun, et al., 2009). Caregivers provided informed consent after being informed about the goal and procedure of the study. They also completed a questionnaire about the socio-economic status of the family. Participants were rewarded with a different book upon completion of the study at each session. The Ethics

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[1] As a reviewer correctly highlighted, while the majority of prime-target pairs overlap in the onset CV, some other pairs overlap along differing dimensions (CCCV, CCCVV, CVV, and CCV). However, we note that removing such trials from the analysis reveal the same pattern of results.

[2] As a result, we produced four possible stimuli combinations: 1) all words had a different gender; 2) all words had the same gender–thus the target and distractor are similarly primed with regards to gender–; 3) target and distractor words had the same gender and it was different to prime gender; or 4) target and distractor had different gender which may overlap with prime (i.e., triplets Müll$_m$– Mütze$_f$ – Tiger$_m$and Butter$_f$ – Pferd$_n$– Schlüssel$_f$; Engl. waste – hat – tiger, and butter – horse – key, respectively). To ensure that the results were not skewed by such gender effects, the final analysis reported excludes trials of the category (4) described above.

Committee of the Institute for Psychology approved the study prior to the start of data collection.

The experiment was presented in an experimental booth, with the child seated either in a car seat or on their caregivers' lap approximately 60cm away from a 40" screen located immediately above the eye tracker, where the stimuli were presented. Loudspeakers hidden above the screen located to the left and right of the screen presented the auditory stimuli.

The Tobii Studio 3.3.2. package was used to present videos to the children during the experiment. Caregivers were asked not to point at the screen or repeat names of the words presented during the study. Gaze data from both eyes were recorded using a Tobii X120 eye tracker. The eye tracker was set to record gaze data at 60 Hz with an average accuracy of 0.5° visual angle. Prior to testing, participants were calibrated using a 5-point calibration procedure. The experiment started only when all points were successfully calibrated for both eyes.

Statistical Analyses

The Dependent Variable

A custom code written in R version 4.0.0 (R Development Core Team, 2019) was used to process fixation data exported from the eye tracker. The eye tracker provides an estimate of X and Y coordinates of children's fixations on the screen, with one datapoint every 16ms. Data from timestamps were only included when the eye tracker reliably acquired data from one or both eyes of the participant. These timestamps were then divided into 40ms time bins. Areas of interest (AOI) on the screen were defined according to the size and location of target and distractor images on screen including a frame of 60 pixels around each image (and a separation of 380 pixels between images). The dependent variable was the proportion of target looking (PTL), namely the proportion of time children spent looking at the target relative to the time they spent looking at the target and distractor. We only included data from 240ms to 2000ms after the onset of the pictures (3440ms to 5200ms into trial) to ensure that only fixations that could reasonably be considered a response to stimulus presentation were included (Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998).

Exclusion Criteria

We applied three trial exclusion criteria. First, we removed those trials in which infants fixated the screen less than 20% of the total duration of the trial (ca. 1140ms). We applied this criterion to eliminate those trials in which participants were not on task (see Borovsky, Ellis, Evans, & Elman, 2015 for a similar approach). Second, we removed those trials in which participants did not fixate both target and distractor images at least once during the trial. This was done to exclude from analyses those trials where the attention of the infant was captured mainly by the visual salience of only one of the displayed images[3]. This exclusion criterion ensured that we

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[3] Following the suggestion of a reviewer, we reran the analysis applying all trial exclusion criteria, except the one where we required children to look at both images on screen for at least one time bin throughout the entire trial. The results of these analyses are presented in the permanent https://osf.io/ yb2k9/ (Avila-Varela, Arias-Trejo & Mani, 2020). Here, we did not find evidence of differences in looking behaviour across related and unrelated trials, regardless of whether the primes and targets were phonologically or semantically related at any of the ages tested. We suggest that this exclusion criterion allows us to ensure that children are on task and peruse all the options being presented to them on-screen rather than fixating

included trials where infants explored the full set of pictures displayed. Third, as noted above, we excluded trials from the analysis where the gender of words was not adequately controlled. After applying these criteria, we excluded the data of eight participants, because they failed to provide at least one trial in all conditions (*Phon-Rel*, *Phon-Unrel*, *Sem-Rel* and *Sem-Unrel*) across the three sessions (eighteen, twenty-one and twenty-four months of age). The subsequent analyses were performed on the remaining data set. See Table 4 for a summary of the total number of trials included for analyses.[4] While the issue of sparse data is an inherent problem in infant research, we consider it necessary to only consider those trials for analyses in which we can ensure that children were on task.

Table 4

Proportion of trials included for analyses.

Age in months	Condition				Total by session
	PhoRel	PhoUnrel	SemRel	SemUnrel	
18-	58.13% (118)	61.69% (124)	50.73% (104)	48.77% (99)	54.80% (445)
21-	60.71% (170)	71.07% (199)	64.16% (179)	62.59% (169)	64.65% (717)
24-	70.77% (201)	74.39% (215)	71.43% (210)	67.26% (189)	70.99% (815)
Total by condition	63.75% (489)	69.87% (538)	63.37% (493)	60.61% (457)	

Note: number of total trials included for analyses in parenthesis.

Statistical Models

All analyses were carried out with linear mixed effects modeling (LMEM) using the lme4 package (version 1.1-23; Bates, Mächler, Bolker, & Walker, 2015) in RStudio (version 1.2.5042; and R version, 4.0.0) with the proportion of target looking as the dependent variable calculated across the time window of 240 to 2000ms following image onset in each trial.[5] We carried out the models for each lexical link separately (*Pho-Rel* and *Phon-Unrel* trials on the one hand, and *Sem-Rel* and *Sem-Unrel* on the other). For each model, we included the maximal random effects structure tolerated by the models (see Barr, Scheepers and Tily, 2013). Please see the annexes section for each model lmer syntax and models outputs.

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a single image, either the target or the distractor throughout the trial. A similar criterion was, as we note earlier, also used in Mani & Plunkett (2010) and Chow et al. (2017) and appears to be critical to capture subtle priming effects at these young ages.

[4] Although the percentage of included trials in the current study may be seem low in comparison with other infant looking studies (i.e., Arias-Trejo & Plunkett, 2009; 2013), where trial inclusion percentages range from 74% to 92% at 18-months, from 95% to 96% at 21-months and 95% at 24-months, we note that in those studies, children were presented with 3 to 4 trials per condition while we presented 6 and 8 trials per condition at 18- and 21-/24-months, respectively.

[5] While we also ran ANOVAs for all the analyses reported, we do not report the results of the ANOVAs here due to the high consistency with the linear mixed effects analyses reported.

Condition (unrelated/related as 1/-1) and Session (Comparison 1: 18-/21-/24-mnoths as 1/0/-1, Comparison 2: 18-/21-/24-months as 0/1/-1) were sum-coded so that the interactions in the model refer to the contrast across conditions or sessions.

We used the drop1 function (function from *stats* package version 3.6.0; R Core Team, 2019) to estimate the effect of removing individual predictors from the full model. Changes in model fit were evaluated using -2 times the change in the likelihood ratio (LRT) which is distributed as chi with chi-square degrees of freedom equal to the number of parameters added for each comparison. Statistical significance (*p*-values) for individual full models´ parameter estimates were assessed using the normal approximation (treating the *t*-value as a *z*-value). In all models, collinearity between variables was checked using the measures *kappa* and the *variance inflation factor* (VIF) from the regression-utils.r and mer-utils.r functions (retrieved from GitHub). In addition, we report the covariance-variance matrix for each model in the Appendixes.[6]

The data and analysis scripts are available on the Open Science Framework at https://osf.io/yb2k9/ (Avila-Varela, Arias-Trejo & Mani, 2020).

The analyses are divided in two parts. We report planned analyses separately examining phonologically and semantically related and unrelated trials as well as the effect of receptive vocabulary on priming effects, while controlling for age. We also examine, where applicable, whether the receptive vocabulary size at the earliest age predicts priming at later ages. Finally, we report exploratory analyses examining whether early priming effects predict later priming effects both withing priming type, e.g., if phonological priming at 18-months predicts phonological priming at 24-months, and across priming type (e.g., whether phonological priming at 18-months predicts semantic priming at 24-months, and vice versa). These analyses were carried out to determine the consistency of the priming effects across the three sessions. Specific models' details are provided in the corresponding results sub-sections and Annexes.

III. Results

Given the crucial role of vocabulary size in the analyses reported below, Table 5 reports the vocabulary size of participants at the different ages. Note that, the vocabulary size entered in the analyses is the total receptive vocabulary[7].

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[6] Deviations from accepted norms in either of these measures (*kappa* > 10 and *VIF* > 3) are reported. Covariance matrixes show values lower than zero.

[7] Although receptive vocabulary is approaching ceiling for some participants, adding productive vocabulary to the models described in this paper lead to the same pattern of results. See https://osf.io/yb2k9/ (Avila-Varela, Arias-Trejo & Mani, 2020).

Table 5

Participants receptive vocabulary size.

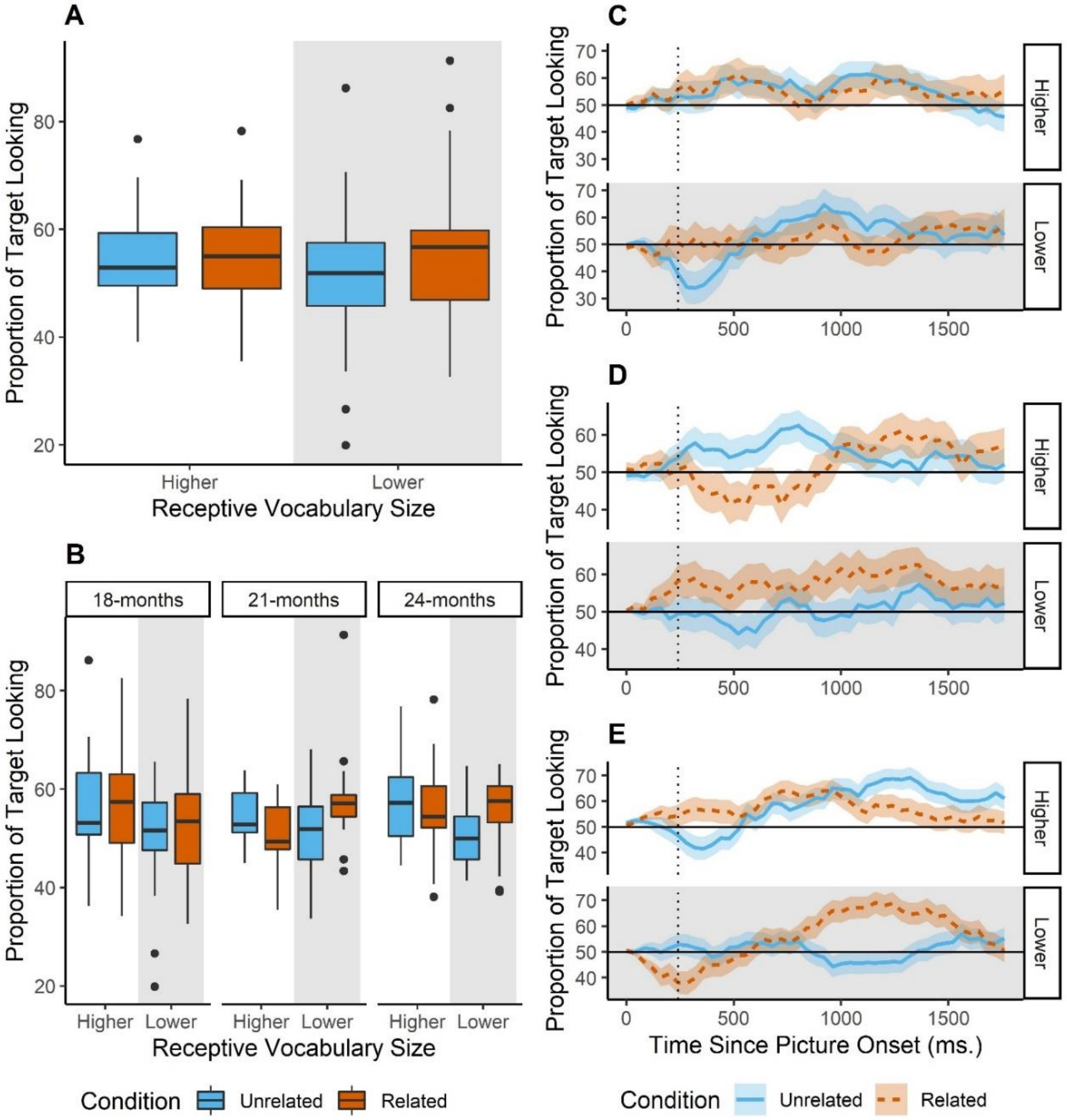
	Receptive vocabulary size			
Age in months	Med	M	SD	Range
18	240	257.03	116.29	44-599
21	416	405.24	96.29	167-599
24	521	501.97	73.41	275-599

Planned Analyses: Phonological Priming

To evaluate the overall effect of receptive vocabulary size on target looking in phonologically related and unrelated trials, we ran a model with PTL as the dependent variable examining the interaction between *Condition* and *Receptive vocabulary size* as well as the interaction between *Condition* and *Session* as fixed effects. We included variation in the intercept and the effect of Condition and Session across participants as random effects (model specification in Appendix C). Drop1 analysis revealed a significant interaction between *Condition* and *Receptive vocabulary* size, despite controlling for age (*Session*), $\chi^2(1) = 4.06$, $p = .043$ (*kappa* = 2.97 and *VIF* = 2.71). Parameter estimates highlighted a significant interaction between *Condition* and *Receptive vocabulary* size, estimate = 0.01, $p = .038$. See Appendix C for the full model output and covariance matrix. Figure 7 depicts this difference between conditions in children with higher and lower vocabulary sizes graphically. Note that vocabulary size was continuous in the model and not discretely split into higher and lower vocabulary size as in the figure. As seen in Figure 7 (A), children looked more at the target image in related trials relative to unrelated trials, i.e., a facilitation effect, with children with smaller vocabularies showing a greater facilitation effect than children with larger vocabularies. Figure 7 (B, C, D and E) plots the phonological priming effect split by vocabulary size at each testing session although we highlight here that we found no statistically significant effects of testing session, i.e., age, on the size of the priming effect.

Figure 7

Proportion of target looking in phonologically related and unrelated trials separated by vocabulary size, averaged across the entire time window across sessions (A), and at each session (B). Time-course of target fixations at 18-months (C), 21-months (D) and 24-months (E) separated by vocabulary size and condition (related and unrelated). Lines represent the mean and ribbons represent SE. Note that participants were grouped according to their receptive vocabulary median split across sessions, although vocabulary size was continuous in the models reported.



Effects of Early Receptive Vocabulary Size on Later Phonological Priming

Next, we examined the extent to which the size of the priming effect at later ages varied as a result of the vocabulary size at the first testing session (18-months). Since vocabulary size at the first testing session was correlated with vocabulary size at later testing sessions, we compared a model adding vocabulary size at 18-months to a model with current vocabulary size at each testing session. This explored whether vocabulary size at 18-months explained more of the variance in target looking relative to the current vocabulary size at each testing session. For the model examining priming at 21-months, we included the interaction between *Condition* and *Receptive vocabulary at 18-months;* and the interaction between *Condition* and *Receptive vocabulary at 21-months* (see Appendix D for model specification). The model tolerated *Participants* and *Condition* at the intercept as random effects. Drop1 analyses found that current vocabulary size (at 21-months) better explained the variance in the priming effect at this age than vocabulary size at 18-months, $\chi^2(1) = 7.00$, $p = .008$; *kappa* = 2.73 and *VIF* = 2.28). In addition, parameter estimates highlighted a significant interaction between *Condition* and *Receptive vocabulary* size at 21-months, estimate = 0.03, $p = .006$. See Appendix D for the full model output. Again, children with lower vocabularies showed a larger facilitation effect than children with higher vocabularies (see Figure 7.B for a graphical depiction of this effect).

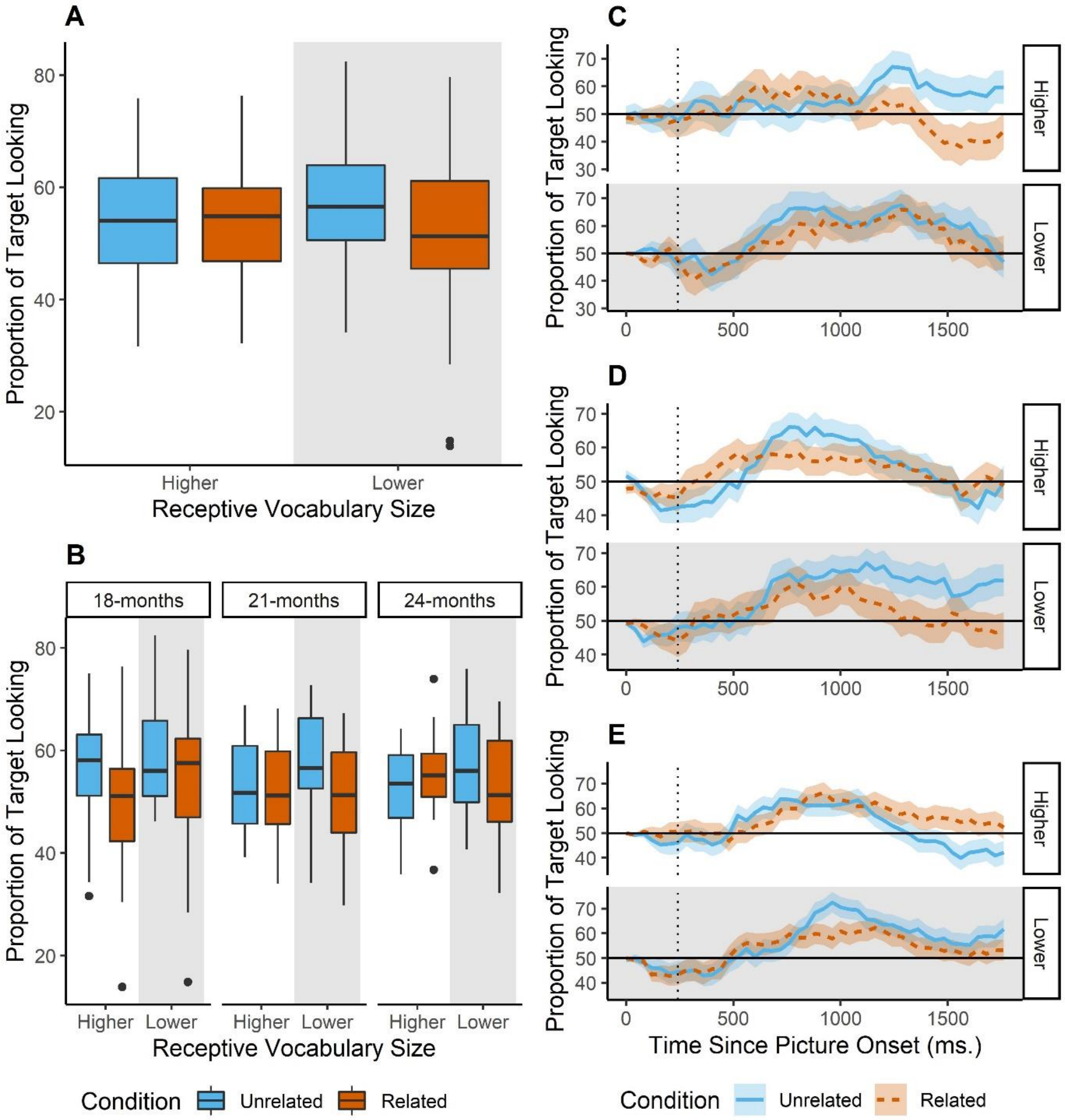
For the model examining priming at 24-months, we included the interaction between *Condition* and *Receptive vocabulary at 18-months* as well as the interaction between *Condition* and *Receptive vocabulary at 24-months.* As random effects, the model tolerated *Participants* and *Condition* at the intercept (see Appendix E for model specification). Drop1 analysis found no evidence for an influence of either initial (18-months) or current (24-months) vocabulary size on variance in the priming effect at this age (*ps* > .4, *kappa* = 2.35 and *VIF* = 1.81), and no evidence for an independent priming effect at this age, *ps* > .3. See Appendix E for the full model output.

Planned Analyses: Semantic priming

To evaluate the overall effect of Receptive vocabulary size on target looking in semantically related and unrelated trials, we ran a model with PTL as the dependent variable including the interaction between *Condition* and *Receptive vocabulary size* as well as the interaction between *Condition* and *Session* as fixed effects. We included variation in the intercept and the effect of Condition and Session across participants as random effects (model specification in Appendix F). The model output revealed a main effect of *Condition* (unrelated vs. related trials, estimate = 1.65, $p = .014$, *kappa* = 2.97 and *VIF* = 2.86) with reduced looks to the target in related relative to unrelated trials (see Appendix F for the full model output). Drop1 analyses found no evidence for an interaction between *Receptive vocabulary size* and *Condition,* nor between *Session* and *Condition*, *ps* > .227. Figure 8 plots the semantic priming effect split by vocabulary size for consistency with the phonological priming data. While this figure suggests that only children with lower vocabularies showed a semantic priming effect, this differentiation by vocabulary size was not significant in the planned analyses.

Figure 8.

Proportion of target looking in semantically related and unrelated trials separated by vocabulary size, averaged across the entire time window across sessions (A), and at each session (B). Time-course of target fixations at 18-months (C), 21-months (D) and 24-months (E) separated by vocabulary size and condition (related and unrelated). Lines represent the mean and ribbons represent SE. Note that participants were grouped according to their receptive vocabulary median split across sessions, although vocabulary size was continuous in the models reported.



Effects of early Receptive vocabulary size on later semantic interference

Next, we examined the extent to which the size of the priming effect at later ages varied as a result of the vocabulary size at the first testing session (18-months) relative to vocabulary size at the current testing session. We follow the same model structures included in the subsection "Effects of early Receptive vocabulary size on later phonological priming", including only the semantically related and unrelated trials. Models to predict priming at 21- and 24-months were carried out separately (*kappa* = 2.73 and *VIF* = 2.28; *kappa* = 2.34 and *VIF* = 1.81; respectively). Neither drop 1 analyses nor the parameter estimates of the full model found a significant effect of early vocabulary size or current vocabulary size on the semantic interference effect at 21- or 24-month-olds (*ps* > .185). See Appendix G and Appendix H for model specification and model outputs for 21- and 24-months, respectively.

Exploratory Analyses: Consistency Within and Across Priming Effects

Effects of Early Performance on Later Performance Within Priming Type

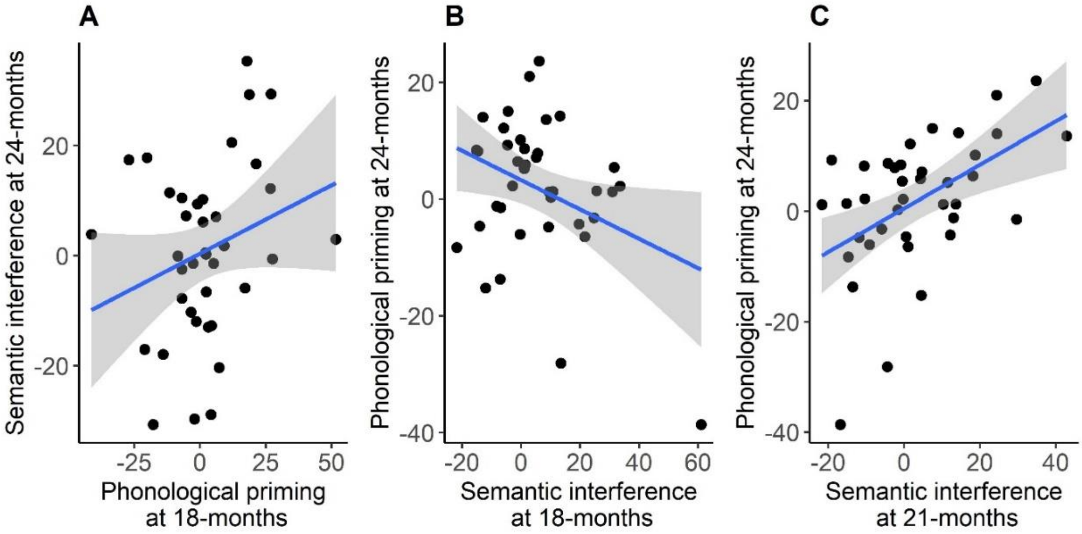
Next, we examined the extent to which performance at the earlier testing points explained variation in the priming effect at the last testing point, separately for the phonological and semantic priming data. To examine the consistency of the priming effect across development, we examined whether the phonological priming effect at 18- and 21-months explained variance in the phonological priming effect at 24-months, and similarly whether the semantic priming effect at 18- and 21-months explained variance in the semantic priming effect at 24-months. Drop 1 analyses found no evidence that the size of the phonological and semantic priming effect in the first two testing sessions predicted the size of the phonological and the semantic priming effect respectively at the last testing session (phonological effect: *ps*>.11; semantic: *ps*>.3). Model specifications and model outputs are available in Appendix I (phonological priming, *kappa* = 1.68 and *VIF* = 1.27) and Appendix J (semantic priming, *kappa* = 1.67 and *VIF* = 1.20).

Effects of Early Performance on Later Performance Across Priming Types

Finally, we explored how sensitivity to one type of overlap between words at earlier ages predicted the sensitivity to the other type of overlap between words studied at later ages. That is, we examine, whether phonological priming effect at 18-months predicted the semantic priming effect at later ages and whether semantic interference effect at 18-months predicted the phonological priming effect at later ages. Model specifications and model outputs examining the influence of phonological priming on semantic priming effects are reported in Appendix K (model *kappa* = 2.19 and *VIF* = 1.37). Model specifications and model outputs examining the influence of semantic priming on phonological priming effects are reported in Appendix L (model *kappa* = 1.73 and *VIF* = 1.21). Despite controlling for *Receptive vocabulary* size, Drop1 analyses found that the *phonological priming at 18-months* explained variance in the semantic interference effect at 24-months, $\chi^2(1) = 4.59$, $p = .032$ (see Appendix K). Similarly, while controlling for *Receptive vocabulary size*, drop 1 analyses show that the semantic interference effect at 18-months ($\chi^2(1) = 4.96$, $p = .025$) and at 21-months of age ($\chi^2(1) = 9.24$, $p = .002$) predicted the phonological priming effect at 24-months, albeit in different directions (see Fig. 4, B and C). However, we also found a main effect of vocabulary size at 24-months in this latter model (estimate = .03, $p = .026$, see Appendix L). Figure 9 plots the correlations identified in the two models. Note that here we plot the reported direction of the semantic and phonological priming effects, since the semantic priming effect was an interference effect while the phonological priming effect was a facilitation effect.

Figure 9

Interaction between phonological and semantic priming effects: Semantic interference at 24-months predicted by phonological priming at 18-months (A), and phonological priming at 24-months predicted by semantic priming at 21- months (B) and at 24-months (C). Ribbons represent the SE and the blue line the fitted linear model.



III. Discussion

The current study aimed at a longitudinal assessment of phonological and semantic priming effects in early childhood, with a particular focus on the role of children's vocabulary size on the development and direction of these effects. Overall, the results suggest variation in priming effects according to children's vocabulary size rather than age at time of testing, at least with regards to phonological priming.

Analysing the phonological priming data, we found overall a phonological facilitation effect – longer fixations to the target in phonologically related trials relative to unrelated trials – which varied in strength with children's vocabulary size, after controlling for age at time of testing. In particular, we found that children with lower vocabulary sizes showed a larger phonological facilitation effect relative to children with higher vocabulary sizes. We found no differentiation in the phonological priming effect across the ages tested, although we note that subsequent analyses found no independent priming effect (or vocabulary modulated priming effect) at 24-months. We did find a vocabulary modulated priming effect at 21-months, with the priming effect being modulated by vocabulary size at time of testing, rather than vocabulary size at the first testing session (18-months). At 21-months, as with the overall analyses, children with lower vocabularies showed a phonological facilitation effect while children with higher vocabularies showed a phonological interference effect. A similar pattern was seen with the 24-month-olds although this effect was not significant at this age.

This parallels to a certain extent the previous literature on phonological priming, while triggering further discussion with regards to the underpinnings of these effect reversals. In particular, Mani & Plunkett (2010, 2011) found that 18-month-olds showed an overall facilitation effect in phonological priming tasks, while the interference effect at 24-month-old was modulated by the cohort size of the individual words tested. Extending those results, the current findings suggest a keen role for vocabulary size in the direction of phonological priming effects, with the size of the phonological facilitation effect being modulated by vocabulary size and potentially changing to a phonological interference effect in children with larger vocabularies (although we note that we only found this to be true of the 21-month-olds and not with the older age-groups). This explanation is also consistent with a recent simulation of early word recognition, suggesting the absence of lexical competition at early ages (18-month-old), and the development of such competition effects between 21- to 24-month-old (Mayor & Plunkett, 2014). Here, we extend this explanation beyond the ages of the infants tested to the vocabulary sizes of the children. In particular, we show that children with lower vocabularies do not display lexical competition effects in phonological word recognition while children with higher vocabularies may show reduced facilitation effects potentially due to increased lexical competition. This finding makes intuitive sense, highlighting the fact that the rapidly expanding vocabulary between 18- to 24-month-old underlies the differences in the priming effects reported to date.

Importantly, applying a longitudinal design (testing the same participants at different ages) allowed us to better delineate the role of vocabulary size on the priming effects reported. First, we found that vocabulary size rather than age better captured the variance in phonological priming effects, even when controlling for age at testing. This highlights the important role of increasing vocabulary knowledge relative to developing cognitive skills on the finding of phonological priming in early childhood. This raises questions of the extent to which differences in the onset of phonological priming effects across individual children or children speaking different languages might be explained with recourse to their vocabulary size. Indeed, while the general pattern of results reported here overlaps with those reported on English-learning children (Mani & Plunkett, 2010, 2011), we note that the ages at which we found a facilitation effect and an interference effect across these studies vary. In particular, we found that German speaking children show a phonological facilitation effect only at 21-months and not necessarily at 18-months (note that we did not find an interaction with age at time of testing so this claim is not statistically supported but the graphical interpretation of the data plotted in Figure 8 suggests such a pattern). Neither did we find that 24-month-old German children displayed a phonological interference effect (again Figure 8 suggests the possibility of such an effect in higher vocabulary 24-month-olds, although this was not significant). It is therefore an important question for future cross-linguistic work to examine whether these admittedly non-significant differences in the pattern of priming effects across German-learning and English-learning children can be explained by differences in the general vocabulary size of children learning these languages. Equally, future research can examine the extent to which differences in vocabulary structure may impact such priming effects across development.

Furthermore, we also found that vocabulary size at the time of testing, at 21-months, better explained the size of the priming effects relative to vocabulary size at the first testing session, at 18-months. This is a significant advancement to our understanding of the role of vocabulary size on lexical structure, against the background of previous longitudinal studies suggesting an influence of early vocabulary size on later priming effects. First, we note that while early vocabulary size was correlated with later vocabulary size and while this did co-vary with later phonological priming effects, a Drop1 analysis found that the interaction between condition and current vocabulary size better explained the priming effects found relative to the interaction with early vocabulary size. In particular, we found an independent contribution of the influence of current vocabulary size on the priming effects reported over and above effects of vocabulary size at 18-months. This finding does not necessarily contradict earlier findings of an influence of early vocabulary size on later priming effects (given the correlation between early and later vocabulary size), but highlights a potentially mediating role of current vocabulary size on priming effects.

Before we discuss the modulation of the semantic priming effect by vocabulary size, we flag here an important concern with our findings, namely the fact that in contrast to most of the previous literature on semantic priming, we consistently find a semantic interference effect. In other words, we find that children look longer at the target in semantically unrelated trials relative to semantically related trials. This was consistent across multiple analyses including those reported in the paper and those available on OSF (e.g., the ANOVAs whose results we do not report here in the interest of brevity). This contrasts with most of the literature on semantic priming effects in early development (Arias-Trejo & Plunkett, 2009, 2013; Styles and Plunkett, 2009, 2011; Torkildsen et al., 2007; Rämä et al., 2013). The only consistency with the literature is the finding that children in a Head Turn Preference Task listened longer to trials presenting children with unrelated stimuli relative to related stimuli (Willits et al., 2013), and with a recent study which found backward semantic inhibitory effects in 18-month-old toddlers with higher vocabulary (Chow, Aimola-Davies, Fuentes & Plunkett, 2018). While we see no reason why our findings should pattern with a different paradigm relative to the one employed in the current study, we highlight some possible reasons for this difference. First, we highlight the timing of presentation of the stimuli. In particular, due to the fact that German nouns must be preceded by a gendered article, the interstimulus interval between prime and target in the current study was increased relative to previous semantic priming studies, e.g., this was 200ms in Arias-Trejo & Plunkett (2009, 2013) relative to the 500ms in the current study. While this reasoning is speculative, we suggest that either the introduction of the gender-inflected article and/or the increased delay between the prime and the target may have led to the differences in the direction of the effect reported here. More importantly, we note that we find a systematic semantic interference using only taxonomically related pairs in this task, while previous studies suggest that it is not until around 21-month-old that any taxonomic interference priming effect is found in children (Arias-Trejo & Plunkett, 2013). Our finding of such effects earlier in development may be due to the increased power in our analyses due to the within-subjects manipulation of age (as part of our longitudinal design) and may tap into subtle interference effects early in development. We note here that the target items presented at test were fully counterbalanced across participants, so it is unlikely that the direction of the effect is influenced by specific properties of the target stimulus. Indeed, the only difference between targets in related and unrelated trials is the relationship between the prime presented prior to the target (which was counterbalanced across sessions and participants, such that, for a given target the same label in some cases was a related prime and in others an unrelated prime).

Notwithstanding the direction of the semantic priming effect, we found no evidence that the strength of the effect was modulated by children's vocabulary size. Neither did we find differential modulation of the semantic priming effect by either current or early vocabulary size. Thus, our results suggest an overall semantic interference effect which did not interact with either age of participants at time of testing or vocabulary size at time of testing, when the other factors were controlled for. Of interest is the extent to which this varies later than 24-months of age, given that studies with English-learning infants suggest it is only at this later age that semantic facilitation effects occur in English-learning infants. It remains possible then that older German-learning infants may show facilitation effects in semantic priming, given the possibility suggested by Figure 9 that the semantic interference effect was stronger in lower vocabulary children at both 21- and 24-months of age, although we highlight here again that this effect was not statistically significant.

Finally, we discuss with some reservation the finding of shared variance in early and later semantic and phonological priming effects. In particular, we found that early phonological priming effects explained some of the variance in later semantic priming effects and vice versa, that early semantic priming effects explained some of the variance in later phonological priming effects. We interpret this finding with some caution given that we did not find evidence for similar shared variation within priming type, i.e., early phonological priming effects did not explain later phonological priming effects and similarly early semantic priming effects did not explain later semantic priming effects. Furthermore, we note that the direction of the influence of the early semantic priming effects on later phonological priming varied between 18- and 21-months of age. Thus reduced semantic priming at 18-months predicted increased phonological priming at 24-months and reduced semantic priming at 21-months predicted reduced phonological priming at 24-months (as we can see in the Figure 9). Given the strong influence on vocabulary size on the phonological priming effects reported, we assume that this may reflect some underlying variation in vocabulary size on the effects (although the model did control for current vocabulary size in examining this relationship). Future research may need to examine with further detail the replicability of this finding and the extent to which such modulation exists outside of mediating effects of vocabulary size.

III. Conclusions

Taken together, our results support earlier findings that children between 18- to 24-month-olds activate phonologically and semantically related words candidates during word recognition. Overall, the simultaneous activation of other word candidates leads to facilitated recognition of phonologically overlapping prime-target pairs, but only in children with smaller vocabulary sizes. This suggests that the phonological facilitation effect may have an underlying phonological bases, with activation of the target being speeded by prior activation of the overlapping phonemes. This phonological facilitation effect may be overridden in children with higher vocabularies due to lexical level competition effects that come in with such higher vocabularies. When considering the semantic links, due to the absence of phonological overlap to support the lexical access of the target label, and despite the presence of semantic overlap, all the other lexical entries (more or less abundant) compete for the lexical access, potentially leading to the overall semantic interference effect reported. This speaks to an important role for vocabulary size in early word recognition and their differential interactions with phonological and semantic lexical links.

III. Acknowledgements

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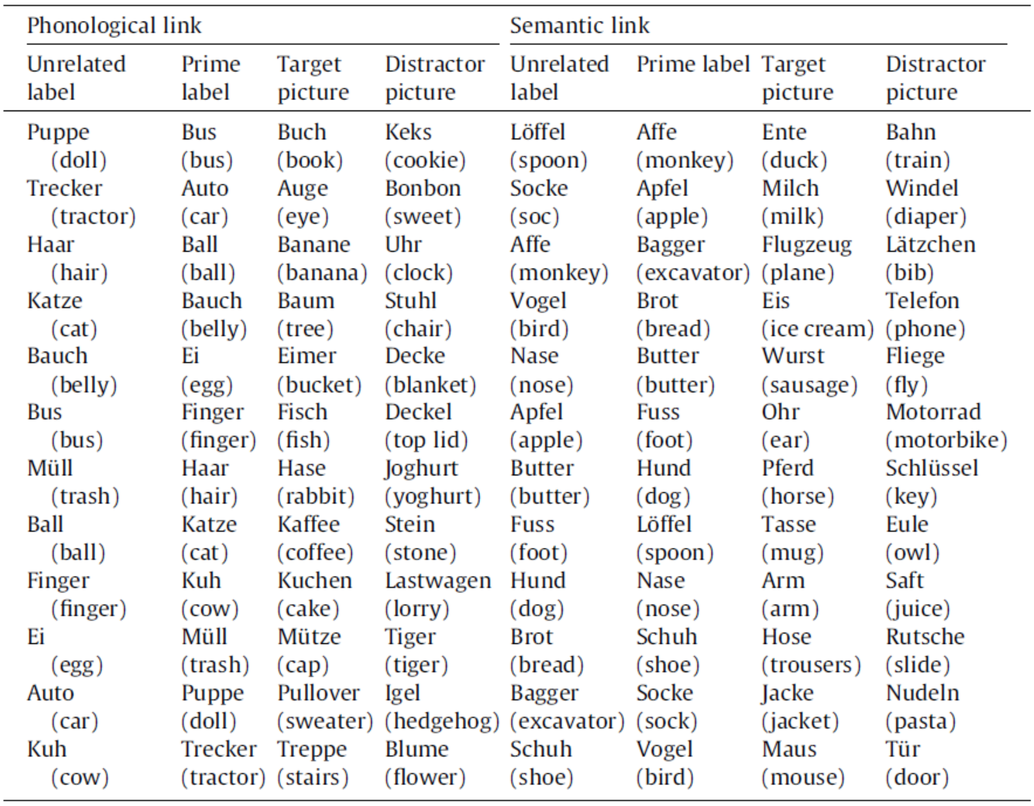
III. Author Contributions

D.S.A-V. and N.M. developed the concept for the study, N.A-T. contributed to the improvement of the study design. Testing and data collection was performed by D.S.A-V. Data analysis were performed by D.S.A-V. and N.M. The manuscript was written by D.S.A-V. and was edited by N.M. and N.A-T. All authors approved the final version of the manuscript for submission

III. Appendix A

Labels Presented at the First Session.



Phonological link				Semantic link			
Unrelated label	Prime label	Target picture	Distractor picture	Unrelated label	Prime label	Target picture	Distractor picture
Puppe (doll)	Bus (bus)	Buch (book)	Keks (cookie)	Löffel (spoon)	Affe (monkey)	Ente (duck)	Bahn (train)
Trecker (tractor)	Auto (car)	Auge (eye)	Bonbon (sweet)	Socke (soc)	Apfel (apple)	Milch (milk)	Windel (diaper)
Haar (hair)	Ball (ball)	Banane (banana)	Uhr (clock)	Affe (monkey)	Bagger (excavator)	Flugzeug (plane)	Lätzchen (bib)
Katze (cat)	Bauch (belly)	Baum (tree)	Stuhl (chair)	Vogel (bird)	Brot (bread)	Eis (ice cream)	Telefon (phone)
Bauch (belly)	Ei (egg)	Eimer (bucket)	Decke (blanket)	Nase (nose)	Butter (butter)	Wurst (sausage)	Fliege (fly)
Bus (bus)	Finger (finger)	Fisch (fish)	Deckel (top lid)	Apfel (apple)	Fuss (foot)	Ohr (ear)	Motorrad (motorbike)
Müll (trash)	Haar (hair)	Hase (rabbit)	Joghurt (yoghurt)	Butter (butter)	Hund (dog)	Pferd (horse)	Schlüssel (key)
Ball (ball)	Katze (cat)	Kaffee (coffee)	Stein (stone)	Fuss (foot)	Löffel (spoon)	Tasse (mug)	Eule (owl)
Finger (finger)	Kuh (cow)	Kuchen (cake)	Lastwagen (lorry)	Hund (dog)	Nase (nose)	Arm (arm)	Saft (juice)
Ei (egg)	Müll (trash)	Mütze (cap)	Tiger (tiger)	Brot (bread)	Schuh (shoe)	Hose (trousers)	Rutsche (slide)
Auto (car)	Puppe (doll)	Pullover (sweater)	Igel (hedgehog)	Bagger (excavator)	Socke (sock)	Jacke (jacket)	Nudeln (pasta)
Kuh (cow)	Trecker (tractor)	Treppe (stairs)	Blume (flower)	Schuh (shoe)	Vogel (bird)	Maus (mouse)	Tür (door)

Note. Original labels presented in the study are in German. Translations to English are in parentheses.

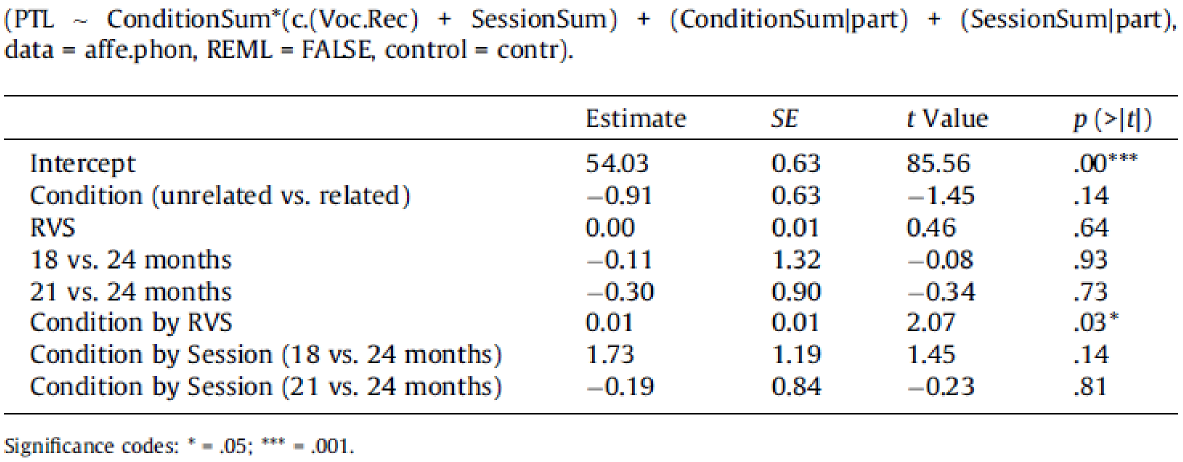
III. Appendix B

Labels Presented at the Second and Third Sessions.

Phonological link				Semantic link			
Unrelated label	Prime label	Target picture	Distractor picture	Unrelated label	Prime label	Target picture	Distractor picture
Puppe (doll)	Bus (bus)	Buch (book)	Keks (cookie)	Löffel (spoon)	Affe (monkey)	Ente (duck)	Bahn (train)
Schaukel (swing)	Auto (car)	Auge (eye)	Bonbon (sweet)	Bein (leg)	Apfel (apple)	Milch (milk)	Windel (diaper)
Teddy (teddy)	Ball (ball)	Banane (banana)	Uhr (clock)	Messer (knife)	Bagger (excavator)	Flugzeug (plane)	Lätzchen (bib)
Katze (cat)	Bauch (belly)	Baum (tree)	Stuhl (chair)	Vogel (bird)	Brot (bread)	Eis (ice cream)	Telefon (phone)
Bauch (belly)	Ei (egg)	Eimer (bucket)	Decke (blanket)	Nase (nose)	Butter (butter)	Wurst (sausage)	Fliege (fly)
Auto (car)	Finger (finger)	Fisch (fish)	Deckel (top lid)	Apfel (apple)	Fuss (foot)	Ohr (ear)	Motorrad (motorcycle)
Ball (ball)	Haar (hair)	Hase (rabbit)	Joghurt (yoghurt)	Schuh (shoe)	Hund (dog)	Pferd (horse)	Schlüssel (key)
Haar (hair)	Katze (cat)	Kaffee (coffee)	Stein (stone)	Socke (sock)	Löffel (spoon)	Tasse (mug)	Eule (owl)
Finger (finger)	Kuh (cow)	Kuchen (cake)	Lastwagen (lorry)	Hund (dog)	Nase (nose)	Arm (arm)	Saft (juice)
Ei (egg)	Müll (trash)	Mütze (cap)	Tiger (tiger)	Butter (butter)	Schuh (shoe)	Hose (trousers)	Rutsche (slide)
Becher (glass)	Puppe (doll)	Pullover (sweater)	Igel (hedgehog)	Fuss (foot)	Socke (sock)	Jack (jacket)	Nudeln (pasta)
Kuh (cow)	Trecker (tractor)	Treppe (stairs)	Blume (flower)	Brot (bread)	Vogel (bird)	Maus (mouse)	Tür (door)
Trecker (tractor)	Becher (glass)	Bett (bed)	Huhn (chicken)	Affe (monkey)	Bein (leg)	Mund (mouth)	Topf (pot)
Müll (trash)	Schaf (sheep)	Schal (scarf)	Ballon (balloon)	Schwein (pig)	Käse (cheese)	Pommes (french fries)	Lampe (lamp)
Bus (bus)	Schaukel (swing)	Schaufel (shovel)	Möhre (carrot)	Bagger (excavator)	Messer (knife)	Flasche (bottle)	Schnecke (slug)
Schaf (sheep)	Teddy (teddy)	Teller (plate)	Besen (broom)	Käse (cheese)	Schwein (pig)	Elefant (elephant)	Tisch (table)

III. Appendix C

Output of the GLM Including the Fixed Effects of Condition, Receptive Vocabulary Size and Session for the Proportion of Target Looking in the Phonological Lexical Link. lmer

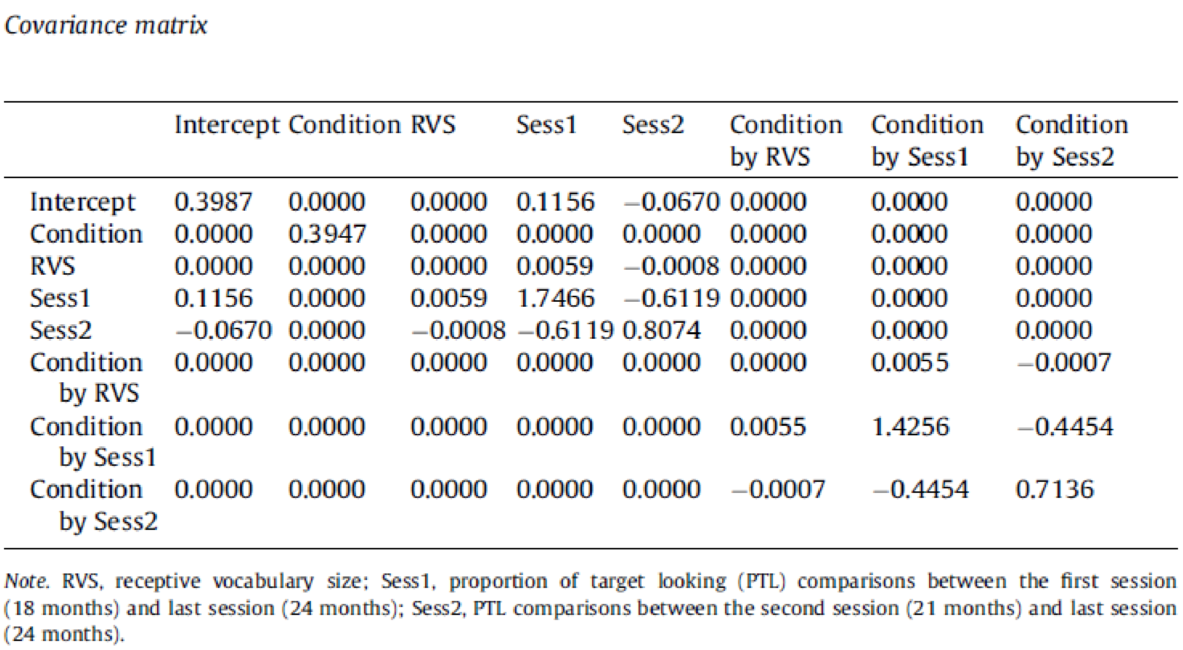


(PTL ~ ConditionSum*(c.(Voc.Rec) + SessionSum) + (ConditionSum|part) + (SessionSum|part), data = affe.phon, REML = FALSE, control = contr).

	Estimate	*SE*	*t* Value	*p* (>|*t*|)
Intercept	54.03	0.63	85.56	.00***
Condition (unrelated vs. related)	−0.91	0.63	−1.45	.14
RVS	0.00	0.01	0.46	.64
18 vs. 24 months	−0.11	1.32	−0.08	.93
21 vs. 24 months	−0.30	0.90	−0.34	.73
Condition by RVS	0.01	0.01	2.07	.03*
Condition by Session (18 vs. 24 months)	1.73	1.19	1.45	.14
Condition by Session (21 vs. 24 months)	−0.19	0.84	−0.23	.81

Significance codes: * = .05; *** = .001.

:



Covariance matrix

	Intercept	Condition	RVS	Sess1	Sess2	Condition by RVS	Condition by Sess1	Condition by Sess2
Intercept	0.3987	0.0000	0.0000	0.1156	−0.0670	0.0000	0.0000	0.0000
Condition	0.0000	0.3947	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RVS	0.0000	0.0000	0.0000	0.0059	−0.0008	0.0000	0.0000	0.0000
Sess1	0.1156	0.0000	0.0059	1.7466	−0.6119	0.0000	0.0000	0.0000
Sess2	−0.0670	0.0000	−0.0008	−0.6119	0.8074	0.0000	0.0000	0.0000
Condition by RVS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0055	−0.0007
Condition by Sess1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0055	1.4256	−0.4454
Condition by Sess2	0.0000	0.0000	0.0000	0.0000	0.0000	−0.0007	−0.4454	0.7136

Note. RVS, receptive vocabulary size; Sess1, proportion of target looking (PTL) comparisons between the first session (18 months) and last session (24 months); Sess2, PTL comparisons between the second session (21 months) and last session (24 months).

III. Appendix D

Output of the GLM Including the Fixed Effects of Condition, Receptive Vocabulary Size at 18- and 21-Month-Olds for the Prediction of Phonological Priming at 21-Months.

```
lmer(PTL ~ ConditionSum*(c.(Voc.rec.in) + c.(Voc.Rec)) + (1 | part) + (1 | ConditionSum),
data=subset(affe.phon, affe.phon$Session=="21-months"), REML=FALSE, control = contr)
```

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	53.78	0.85	63.26	0.00***
Condition (unrelated vs. related)	-0.88	0.85	-1.03	0.30
Receptive Vocabulary Size (RVS) at 18-months	0.01	0.01	0.64	0.51
RVS at 21-months	-0.02	0.01	-1.36	0.17
Condition by RVS at 18-months	0.00	0.01	-0.11	0.90
Condition by RVS at 21-months	0.04	0.01	2.71	0.00**

Signif. codes: 0.001 '***' 0.01 '**' 0.05 '*'

Covariance Matrix

	Int.	Cond.	RVS-18	RVS-21	Cond. by RVS-18	Cond. by RVS-21
Int.	0.7226	0.0000	0.0000	0.0000	0.0000	0.0000
Cond.	0.0000	0.7226	0.0000	0.0000	0.0000	0.0000
RVS -18	0.0000	0.0000	0.0001	-0.0001	0.0000	0.0000
RVS -21	0.0000	0.0000	-0.0001	0.0002	0.0000	0.0000
Cond. by RVS-18	0.0000	0.0000	0.0000	0.0000	0.0001	-0.0001
Cond. by RVS-21	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0002

III. Appendix E

Output of the GLM Including the Fixed Effects of Condition, Receptive Vocabulary Size at 18- and 24-Month-Olds for the Prediction of Phonological Priming at 24-Months.

```
lmer(PTL ~ ConditionSum*(c.(Voc.rec.in) + c.(Voc.Rec)) + (1 | part) + (1 | ConditionSum), data=subset(affe.phon, affe.phon$Session=="24-months"), REML=FALSE, control = contr)
```

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	54.79	0.93	59.15	0.00***
Condition (unrelated vs. related)	-0.92	0.93	-1.00	0.31
Receptive Vocabulary Size (RVS) at 18-months	0.01	0.01	1.37	0.16
RVS at 24-months	0.01	0.02	0.49	0.62
Condition by RVS at 18-months	0.01	0.01	0.79	0.43
Condition by RVS at 24-months	0.01	0.02	0.35	0.72

Signif. codes: 0.001 '***' 0.01 '**' 0.05 '*'

Covariance Matrix

	Int.	Cond.	RVS-18	RVS-24	Cond. by RVS-18	Cond. by RVS-24
Int.	0.8579	0.0000	0.0000	0.0000	0.0000	0.0000
Cond.	0.0000	0.8579	0.0000	0.0000	0.0000	0.0000
RVS -18	0.0000	0.0000	0.0001	-0.0001	0.0000	0.0000
RVS -24	0.0000	0.0000	-0.0001	0.0003	0.0000	0.0000
Cond. by RVS-18	0.0000	0.0000	0.0000	0.0000	0.0001	-0.0001
Cond. by RVS-24	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0003

III. Appendix F

Output of the generalized linear model including the fixed effects of condition, receptive vocabulary size, and session for the proportion of target looking in the semantic lexical link: lmer(PTL ~ ConditionSum*(c.(Voc.Rec) + SessionSum) + (SessionSum | part) + (ConditionSum| part), data = affe.sem, REML = FALSE, control = contr).

	Estimate	*SE*	*t* Value	*p* (>|*t*|)
Intercept	54.20	0.81	66.99	.00***
Condition (unrelated vs. related)	1.65	0.67	2.44	.01*
RVS	−0.01	0.01	−1.03	.30
18 vs. 24 months	−0.55	1.56	−0.35	.72
21 vs. 24 months	−0.39	0.99	−0.40	.69
Condition by RVS	−0.01	0.01	−1.21	.22
Condition by Session (18 vs. 24 months)	0.07	1.31	0.05	.96
Condition by Session (21 vs. 24 months)	0.21	0.94	0.23	.82

Significance codes: * = .05; *** = .001.

Covariance matrix

	Intercept	Condition	RVS	Sess1	Sess2	Condition by RVS	Condition by Sess1	Condition by Sess2
Intercept	0.6545	−0.0175	0.0000	0.2956	−0.1478	0.0000	0.0000	0.0000
Condition	−0.0175	0.4549	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RVS	0.0000	0.0000	0.0001	0.0089	−0.0012	0.0000	−0.0002	0.0000
Sess1	0.2956	0.0000	0.0089	2.4452	−0.7909	−0.0002	−0.0269	0.0035
Sess2	−0.1478	0.0000	−0.0012	−0.7909	0.9852	0.0000	0.0035	−0.0005
Condition by RVS	0.0000	0.0000	0.0000	−0.0002	0.0000	0.0000	0.0065	−0.0008
Condition by Sess1	0.0000	0.0000	−0.0002	−0.0269	0.0035	0.0065	1.7070	−0.5415
Condition by Sess2	0.0000	0.0000	0.0000	0.0035	−0.0005	−0.0008	−0.5415	0.8761

Note. RVS, receptive vocabulary size; Sess1, proportion of target looking (PTL) comparisons between the first session (18 months) and last session (24 months). Sess2, PTL comparisons between the second session (21 months) and last session (24 months).

III. Appendix G

Output of the GLM Including the Fixed Effects of Condition, Receptive Vocabulary Size at 18- and 21-Month-Olds for the Prediction of Semantic Interference at 21-Months. lmer(PTL ~ ConditionSum*(c.(Voc.rec.in) + c.(Voc.Rec)) + (1 | part) + (1 | ConditionSum), data=subset(affe.sem, affe.sem$Session=="21-months"), REML=FALSE, control = contr)

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	53.66	1.06	50.71	0.00***
Condition (unrelated vs. related)	1.71	1.06	1.62	0.10
Receptive Vocabulary Size (RVS) at 18-months	0.01	0.01	0.63	0.52
RVS at 21-months	-0.02	0.02	-1.38	0.16
Condition by RVS at 18-months	-0.02	0.01	-1.33	0.18
Condition by RVS at 21-months	-0.01	0.02	-0.54	0.59

Signif. codes: 0.001 '***' 0.01 '**' 0.05 '*'

Covariance Matrix

	Int.	Cond.	RVS-18	RVS-21	Cond. by RVS-18	Cond. by RVS-21
Int.	1.1196	0.0000	0.0000	0.0000	0.0000	0.0000
Cond.	0.0000	1.1196	0.0000	0.0000	0.0000	0.0000
RVS -18	0.0000	0.0000	0.0002	-0.0002	0.0000	0.0000
RVS -21	0.0000	0.0000	-0.0002	0.0003	0.0000	0.0000
Cond. by RVS-18	0.0000	0.0000	0.0000	0.0000	0.0002	-0.0002
Cond. by RVS-21	0.0000	0.0000	0.0000	0.0000	-0.0002	0.0003

III. Appendix H

Output of the GLM Including the Fixed Effects of Condition, Receptive Vocabulary Size at 18- and 24-Month-Olds for the Prediction of Semantic Interference at 24-Months. lmer(PTL ~ ConditionSum*(c.(Voc.rec.in) + c.(Voc.Rec)) + (1 | part) + (1 | ConditionSum), data=subset(affe.sem, affe.sem$Session=="24-months"), REML=FALSE, control = contr)

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	54.17	1.08	49.96	0.00***
Condition (unrelated vs. related)	0.40	1.08	0.37	0.71
Receptive Vocabulary Size (RVS) at 18-months	-0.00	0.01	-0.37	0.71
RVS at 24-months	0.01	0.02	0.26	0.79
Condition by RVS at 18-months	0.01	0.01	0.86	0.38
Condition by RVS at 24-months	-0.01	0.02	-0.43	0.67

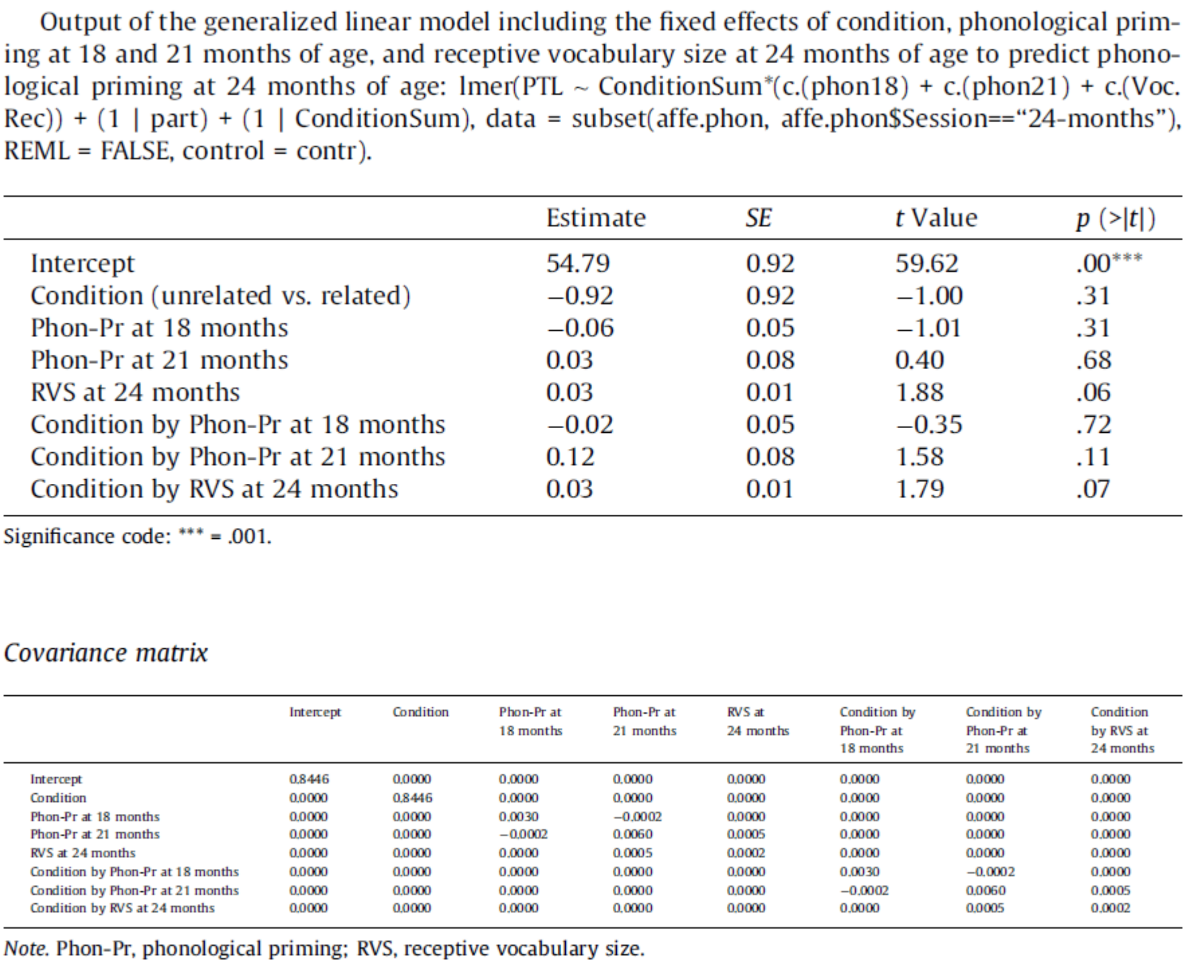
Signif. codes: 0.001 '***' 0.01 '**' 0.05 '*'

Covariance Matrix

	Int.	Cond.	RVS-18	RVS-24	Cond. by RVS-18	Cond. by RVS-24
Int.	1.1756	0.0000	0.0000	0.0000	0.0000	0.0000
Cond.	0.0000	1.1756	0.0000	0.0000	0.0000	0.0000
RVS -18	0.0000	0.0000	0.0002	-0.0002	0.0000	0.0000
RVS -24	0.0000	0.0000	-0.0002	0.0004	0.0000	0.0000
Cond. by RVS-18	0.0000	0.0000	0.0000	0.0000	0.0002	-0.0002
Cond. by RVS-24	0.0000	0.0000	0.0000	0.0000	-0.0002	0.0004

III. Appendix I

Output of the GLM Including the Fixed Effects of Condition, Phonological Priming at 18- and 21-Months; and Receptive Vocabulary Size at 24-Months to Predict Phonological Priming at 24-Months. lmer(PTL ~ ConditionSum*(c.(phon18) + c.(phon21) + c.(Voc.Rec)) + (1 | part) + (1 | ConditionSum), data=subset(affe.phon, affe.phon$Session=="24-months"), REML=FALSE, control = contr)



Output of the generalized linear model including the fixed effects of condition, phonological priming at 18 and 21 months of age, and receptive vocabulary size at 24 months of age to predict phonological priming at 24 months of age: lmer(PTL ~ ConditionSum*(c.(phon18) + c.(phon21) + c.(Voc.Rec)) + (1 | part) + (1 | ConditionSum), data = subset(affe.phon, affe.phon$Session==“24-months”), REML = FALSE, control = contr).

	Estimate	*SE*	*t* Value	*p* (>|*t*|)
Intercept	54.79	0.92	59.62	.00***
Condition (unrelated vs. related)	−0.92	0.92	−1.00	.31
Phon-Pr at 18 months	−0.06	0.05	−1.01	.31
Phon-Pr at 21 months	0.03	0.08	0.40	.68
RVS at 24 months	0.03	0.01	1.88	.06
Condition by Phon-Pr at 18 months	−0.02	0.05	−0.35	.72
Condition by Phon-Pr at 21 months	0.12	0.08	1.58	.11
Condition by RVS at 24 months	0.03	0.01	1.79	.07

Significance code: *** = .001.

Covariance matrix

	Intercept	Condition	Phon-Pr at 18 months	Phon-Pr at 21 months	RVS at 24 months	Condition by Phon-Pr at 18 months	Condition by Phon-Pr at 21 months	Condition by RVS at 24 months
Intercept	0.8446	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Condition	0.0000	0.8446	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Phon-Pr at 18 months	0.0000	0.0000	0.0030	−0.0002	0.0000	0.0000	0.0000	0.0000
Phon-Pr at 21 months	0.0000	0.0000	−0.0002	0.0060	0.0005	0.0000	0.0000	0.0000
RVS at 24 months	0.0000	0.0000	0.0000	0.0005	0.0002	0.0000	0.0000	0.0000
Condition by Phon-Pr at 18 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0030	−0.0002	0.0000
Condition by Phon-Pr at 21 months	0.0000	0.0000	0.0000	0.0000	0.0000	−0.0002	0.0060	0.0005
Condition by RVS at 24 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0002

Note. Phon-Pr, phonological priming; RVS, receptive vocabulary size.

III. Appendix J

Output of the generalized linear model including the fixed effects of condition, semantic interference at 18 and 21 months of age, and receptive vocabulary size at 24 months of age to predict semantic interference at 24 months of age: lmer(PTL ~ ConditionSum*(c.(sem18) + c.(sem21) + c.(Voc.Rec)) + (1 | part) + + (1 | ConditionSum), data = subset(affe.sem, affe.sem$Session==“24-months”), REML = FALSE, control = contr).

	Estimate	*SE*	*t* Value	*p* (>|*t*|)
Intercept	54.17	1.07	50.77	.00***
Condition (unrelated vs. related)	0.40	1.07	0.38	.70
Sem-Int at 18 months	−0.09	0.07	−1.41	.15
Sem-Int at 21 months	−0.03	0.08	−0.35	.72
RVS at 24 months	0.00	0.02	0.07	.94
Condition by Sem-Int at 18 months	−0.04	0.07	−0.60	.55
Condition by Sem-Int at 21 months	−0.08	0.08	−1.04	.30
Condition by RVS at 24 months	0.00	0.02	−0.14	.89

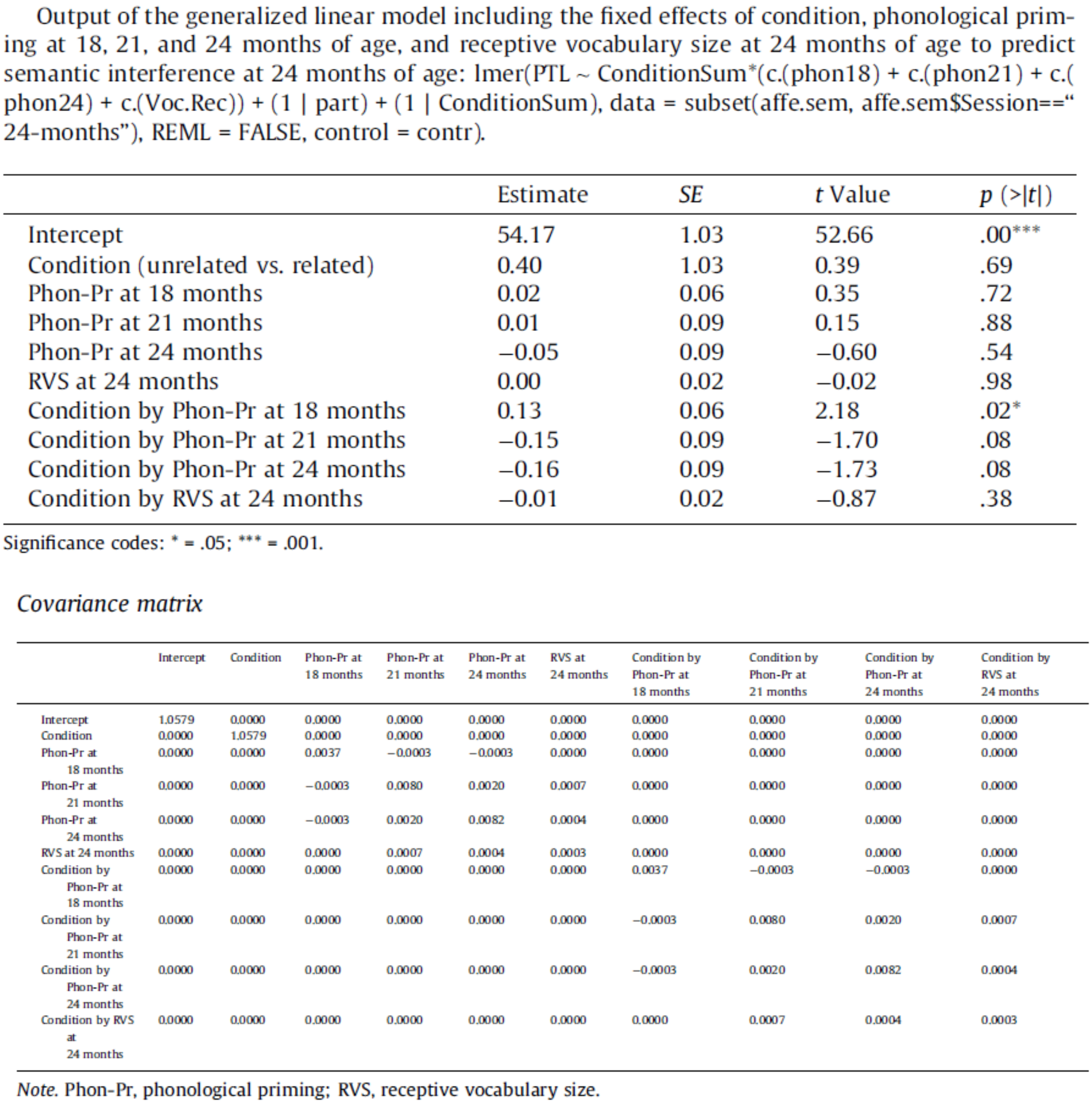
Significance code: *** = .001.

Covariance matrix

	Intercept	Condition	Sem-Int at 18 months	Sem-Int at 21 months	RVS at 24 months	Condition by Sem-Int at 18 months	Condition by Sem-Int at 21 months	Condition by RVS at 24 months
Intercept	1.1385	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Condition	0.0000	1.1385	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sem-Int at 18 months	0.0000	0.0000	0.0043	0.0003	−0.0001	0.0000	0.0000	0.0000
Sem-Int at 21 months	0.0000	0.0000	0.0003	0.0059	0.0005	0.0000	0.0000	0.0000
RVS at 24 months	0.0000	0.0000	−0.0001	0.0005	0.0003	0.0000	0.0000	0.0000
Condition by Sem-Int at 18 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0043	0.0003	−0.0001
Condition by Sem-Int at 21 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0059	0.0005
Condition by RVS at 24 months	0.0000	0.0000	0.0000	0.0000	0.0000	−0.0001	0.0005	0.0003

Note. Sem-Int, semantic interference; RVS, receptive vocabulary size.

III. Appendix K



Output of the generalized linear model including the fixed effects of condition, phonological priming at 18, 21, and 24 months of age, and receptive vocabulary size at 24 months of age to predict semantic interference at 24 months of age: lmer(PTL ~ ConditionSum*(c.(phon18) + c.(phon21) + c.(phon24) + c.(Voc.Rec)) + (1 | part) + (1 | ConditionSum), data = subset(affe.sem, affe.sem$Session==“ 24-months”), REML = FALSE, control = contr).

	Estimate	*SE*	*t* Value	*p* (>|*t*|)
Intercept	54.17	1.03	52.66	.00***
Condition (unrelated vs. related)	0.40	1.03	0.39	.69
Phon-Pr at 18 months	0.02	0.06	0.35	.72
Phon-Pr at 21 months	0.01	0.09	0.15	.88
Phon-Pr at 24 months	−0.05	0.09	−0.60	.54
RVS at 24 months	0.00	0.02	−0.02	.98
Condition by Phon-Pr at 18 months	0.13	0.06	2.18	.02*
Condition by Phon-Pr at 21 months	−0.15	0.09	−1.70	.08
Condition by Phon-Pr at 24 months	−0.16	0.09	−1.73	.08
Condition by RVS at 24 months	−0.01	0.02	−0.87	.38

Significance codes: * = .05; *** = .001.

Covariance matrix

	Intercept	Condition	Phon-Pr at 18 months	Phon-Pr at 21 months	Phon-Pr at 24 months	RVS at 24 months	Condition by Phon-Pr at 18 months	Condition by Phon-Pr at 21 months	Condition by Phon-Pr at 24 months	Condition by RVS at 24 months
Intercept	1.0579	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Condition	0.0000	1.0579	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Phon-Pr at 18 months	0.0000	0.0000	0.0037	−0.0003	−0.0003	0.0000	0.0000	0.0000	0.0000	0.0000
Phon-Pr at 21 months	0.0000	0.0000	−0.0003	0.0080	0.0020	0.0007	0.0000	0.0000	0.0000	0.0000
Phon-Pr at 24 months	0.0000	0.0000	−0.0003	0.0020	0.0082	0.0004	0.0000	0.0000	0.0000	0.0000
RVS at 24 months	0.0000	0.0000	0.0000	0.0007	0.0004	0.0003	0.0000	0.0000	0.0000	0.0000
Condition by Phon-Pr at 18 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0037	−0.0003	−0.0003	0.0000
Condition by Phon-Pr at 21 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	−0.0003	0.0080	0.0020	0.0007
Condition by Phon-Pr at 24 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	−0.0003	0.0020	0.0082	0.0004
Condition by RVS at 24 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007	0.0004	0.0003

Note. Phon-Pr, phonological priming; RVS, receptive vocabulary size.

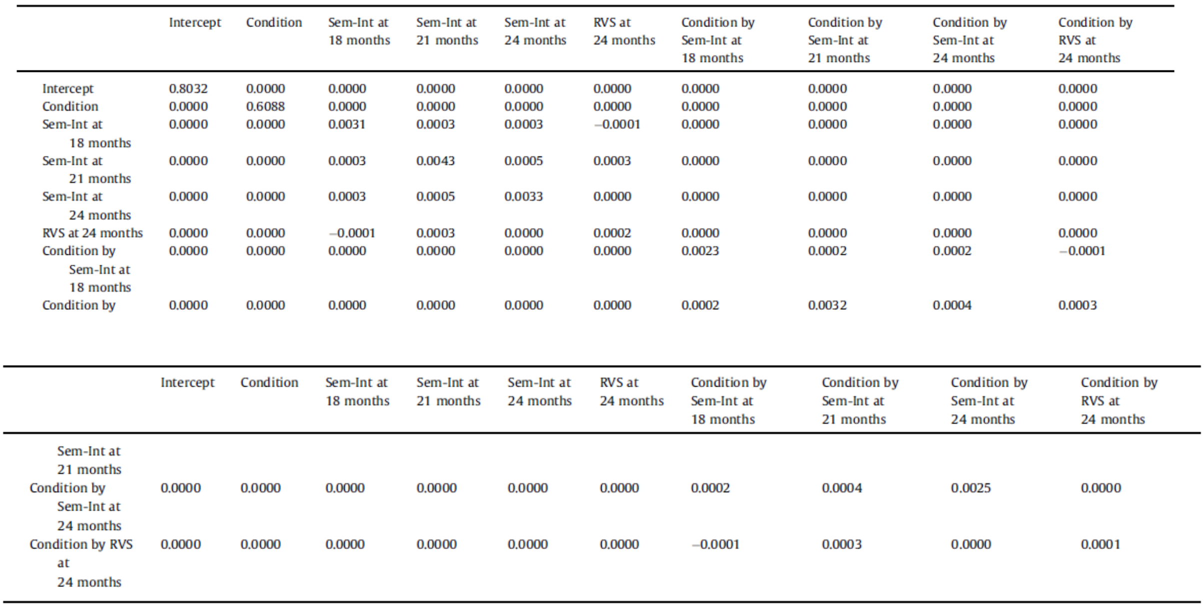
III. Appendix L

Output of the GLM Including the Fixed Effects of Condition, Semantic Interference at 18-, 21- and 24-Months; and Receptive Vocabulary Size at 24-Months to Predict Phonological Priming at 24-Months. lmer(PTL ~ ConditionSum*(c.(sem18) + c.(sem21) + c.(sem24)+ c.(Voc.Rec)) + (1 | part) + (1 | ConditionSum), data=subset(affe.phon, affe.phon$Session=="24-months"), REML=FALSE, control = contr)

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	54.79	0.90	61.13	0.00***
Condition (unrelated vs. related)	-0.92	0.78	-1.18	0.23
Semantic Interference (Sem-Int) at 18-months	-0.01	0.06	-0.26	0.79
Sem-Int at 21-months	0.06	0.07	0.90	0.37
Sem-Int at 24-months	-0.08	0.06	-1.31	0.19
Receptive Vocabulary Size (RVS) at 24-months	0.03	0.01	2.22	0.02*
Condition by Sem-Int at 18-months	0.11	0.05	2.30	0.02*
Condition by Sem-Int at 21-months	-0.18	0.06	-3.24	0.00**
Condition by Sem-Int at 24-months	0.05	0.05	0.95	0.34
Condition by RVS at 24-months	0.00	0.01	-0.37	0.71

Signif. codes: 0.001 '***' 0.01 '**' 0.05 '*'

Covariance matrix



	Intercept	Condition	Sem-Int at 18 months	Sem-Int at 21 months	Sem-Int at 24 months	RVS at 24 months	Condition by Sem-Int at 18 months	Condition by Sem-Int at 21 months	Condition by Sem-Int at 24 months	Condition by RVS at 24 months
Intercept	0.8032	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Condition	0.0000	0.6088	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sem-Int at 18 months	0.0000	0.0000	0.0031	0.0003	0.0003	−0.0001	0.0000	0.0000	0.0000	0.0000
Sem-Int at 21 months	0.0000	0.0000	0.0003	0.0043	0.0005	0.0003	0.0000	0.0000	0.0000	0.0000
Sem-Int at 24 months	0.0000	0.0000	0.0003	0.0005	0.0033	0.0000	0.0000	0.0000	0.0000	0.0000
RVS at 24 months	0.0000	0.0000	−0.0001	0.0003	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
Condition by Sem-Int at 18 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0023	0.0002	0.0002	−0.0001
Condition by Sem-Int at 21 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0032	0.0004	0.0003
Condition by Sem-Int at 24 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0004	0.0025	0.0000
Condition by RVS at 24 months	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	−0.0001	0.0003	0.0000	0.0001

Note. Sem-Int, semantic interference; RVS, receptive vocabulary size.

Chapter IV. Avila-Varela, Jones & Mani (2022)

Avila-Varela, D. S., Jones, G. & Mani, N. (2022). Effects of words’ phonological and phono-semantic overlap in toddlers’ word recognition. Unpublished manuscript.

Effects of Words’ Phonological and Phono-semantic Overlap in Toddlers’ Word Recognition

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All authors have not conflicts of interest to disclose.

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IV. Abstract

Research on the effects of phonological and semantic overlap between words in toddlers' spoken word recognition have shown a trend towards interference effects as the child grows up and her vocabulary increases (Avila-Varela et al., 2021; Mani & Plunkett, 2011; Chow et al., 2018; Angulo-Chavira & Arias-Trejo, 2021). These sources of overlap have been studied applying the additive priming paradigm independently', i.e., phonological overlap on the one hand (Mani & Plunkett, 2010, 2011) and semantic overlap on the other (Arias-Trejo & Plunkett, 2009, 2013). In contrast, the combined phonological and semantic overlap between words has been studied applying the mediated priming paradigm (Mani et al., 2012; Angulo-Chavira & Arias-Trejo, 2018, 2021). Nevertheless, the advantage of the additive priming paradigm is that it allows one to study the impact of different sources of overlap between words at the same phase/stage of processing. Therefore, in the current study we tested phonological and phono-semantic priming effects in 21-month-old monolingual British children applying the additive priming paradigm. Although total looking time showed an advantage in target recognition in phono-semantic trials over phonological trials, growth curve analysis indicated interference effects on word recognition for both lexical links (phonological and phono-semantic). Together, the results suggest lower interference in target recognition under phono-semantic overlap than for phonological overlap alone. These results align with the Distributed Cohort Model of spoken word recognition (Gaskell & Marslen-Wilson, 1997), as the semantic overlap added to phonologically related words might have narrowed down the potential words for recognition, thus reducing the interference on recognition.

Keywords: toddlers, eye tracking, word recognition, phono-semantic relatedness, early lexicon.

Effects of Words' Phonological and Phono-Semantic Overlap in Toddlers' Word Recognition

How do a word´s phonemes and their associated meaning impacts on its recognition? This question has been the focus of psycholinguistic research in the last decades. When disentangling the factors involved in word recognition in early childhood, research has found that toddlers, like adults, recognise the referent of a familiar word soon after hearing even just the first phonemes of the label (Fernald et al., 2001). In addition, throughout their growth, children become faster and more accurate when recognising words (Fernald et al., 1998). With this in mind, the current study will examine the specific role of the combination of phonological and semantic aspects in word recognition in toddlers. In what follows, literature on the influence of relatedness on word recognition will be reviewed, first on the effect of phonological overlap alone, then on semantic overlap alone and finally, on combined phonological and semantic overlap.

The study of lexical links in the early lexicon has classically been explored by applying the additive priming adaption of the intermodal preferential looking paradigm (IPL, Golinkoff et al., 1987). In the original IPL paradigm, two pictures are presented side by side on a screen (e.g., an *apple* and a *table*), later an audio recording of one of the images is named (e.g., Oh! Look at the *apple*!). In the additive priming adaptation of this task, the images and the target labels are preceded by a prime stimulus, which is either a label or an image that shares phonological, semantic (or both) features with the target (e.g., Arias-Trejo & Plunkett, 2009; Avila-Varela, Arias-Trejo, et al., 2021; Mani & Plunkett, 2010). Typically, the initial presentation of a related prime—label or image—leads to either an improvement or interference in target recognition relative to target recognition when previously an unrelated prime was presented. Priming effects in the direction of facilitation have been indexed by increased fixations at the target when it is preceded by a related prime relative to an unrelated prime. Interference effects, on the other hand, are indexed by an increase on fixations at the target when it is preceded by an unrelated prime relative to a related prime.

Applying the additive priming paradigm to the study of phonological links in the early lexicon suggests that two-year-old toddlers look longer at the target (e.g., *dog*) when an unrelated prime precedes it (e.g., *boat*) compared to a related prime (e.g., *door*, Mani & Plunkett, 2011) while younger children display the opposite effect. That is, 18-month-olds look faster and longer at the target object when a phonologically related prime precedes it compared to an unrelated prime (Mani & Plunkett, 2010a). This shift has been attributed to the increasing number of phonologically similar sounding words known by older children, which is supported by the finding that phonological interference effects are mediated by the cohort size (i.e., the number of phonological neighbours) of prime and target words (Mani & Plunkett, 2011). In this direction, a recent longitudinal study (at 18, 21 and 24 months of age) found that participants' phonological priming was predicted by their current receptive vocabulary size (i.e., the higher their vocabulary, the higher the interference in target recognition, Avila-Varela et al., 2021).

On the other hand, studies examining children's sensitivity to a word´s semantic overlap, implementing the additive priming paradigm, found that 21-month-old´s spoken word recognition is improved when primed with taxonomic and associative words (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009, 2011). Later, at 24 months of age, children show sensitivity to purely associative words (i.e., words that frequently co-occur in language, e.g., dog-bone) or purely taxonomic words (i.e., exemplars belonging to the same supra-ordinate category, e.g., dog-chicken) (Arias-Trejo & Plunkett, 2013). Furthermore, recent studies applying simplified versions of the intermodal preferential looking paradigm report earlier semantic priming in younger children between 12 and 14 months of age (Bergelson & Aslin, 2017). In contrast, studies implementing simplified tasks such as the Head Turn Preference Procedure, where children only hear lists of semantically related words (e.g., “dog”, “cat”, “cow”) and lists of unrelated words (e.g., “dog”, “shoe”, “biscuit”) report priming effects in 18- and 24-month-old children (Delle Luche et al., 2014; Willits et al., 2013). These findings highlight that children are sensitive to the semantic links between words before the second year of life.

In addition, some research has studied the impact of both phonological and semantic overlap on young children’s word recognition (e.g., Altvater-Mackensen & Mani, 2013a; Angulo-Chavira & Arias-Trejo, 2018; Chow et al., 2017; Huang & Snedeker, 2011; Huettig & McQueen, 2007; Mani et al., 2012). For instance, Huang & Snedeker (2010) presented 5-year-old children with a task where they had to pick a card matching a target label, and their eye movements were recorded. Among the four cards, one contained the target (e.g., “moose”), a semantically related to an absent member of the target’s phonological cohort (e.g., “sun”), and two unrelated distractors (e.g., “ladle” and “watermelon”). Here the target “moose” was phonologically related to the word “moon”, which was semantically related to the word “sun”. Therefore, the only way for “moose” to facilitate the recognition of the word “sun” is through the activation of the phono-semantically associate word “moon”. The authors found that 5-year-children, like adults, (Marslen-Wilson & Zwitserlood, 1989; Yee & Sedivy, 2006) activate phonologically related words to the heard target and activate semantically related words to them.

The importance of considering the interplay of phonological and semantic representations is highlighted by findings in the literature that report a “tug-of-war” between phonological and semantic processes; these indicate a cascaded retrieval of initially phonological codes and later semantic or perceptual content to matching a spoken word to its referent (Chow et al., 2017; Huettig & McQueen, 2007; Mani et al., 2012).

Additional research also found that 2-year-old children show activation from phonological and semantic related words (Altvater-Mackensen & Mani, 2013a; Angulo-Chavira & Arias-Trejo, 2018, 2021; Mani et al., 2012). Those studies instead applied the intermodal-preferential looking task adapted to a mediated priming paradigm where only two images are displayed (and not four as in the visual-world-paradigm). In Mani et al.’s study (2012), 2-year-old children were presented with a prime stimulus that was phonologically related at the onset (Exp. 1) or at the rhyme (Exp. 2) with a mediating word, which was semantically related to the displayed target image. Here, for example, the only way for a word like “clock” to facilitate the recognition of the word “shoe” is through the activation of a phono-semantically related word such as “sock”. The results show that 2-year-old children, as older children and adults, also display phono-semantic priming effects.

More recently, a mediated priming study by Angulo-Chavira & Arias-Trejo (2018) with Spanish speaking toddlers found a bidirectional activation between semantic and phonologically word associates. They replicated the forward phonological to semantic activation previously reported in Mani et al. (2012) and Altvater-Mackensen & Mani (2013a) with 2-year-olds. Also, they found that a prime image (e.g., “dog”) activated a semantic related word (e.g., “cat”), which then facilitated the recognition of a phonologically related target (e.g., “cup”), yet only in older children of 30 months of age. This result indicates that while cascaded activation from phonological to semantically related words occur at 24 months, the reverse order of activation (i.e., activation from semantically related words to phonologically related words) is possible only from 30 months of age.

Against this background, the current study examines the influence of semantic and phonological overlap between words on lexical recognition in young children. In particular, we note that previous studies examining the phonological and semantic organisation of the early lexicon have investigated them separately (phonological and semantic in *additive* priming studies) or at different stages in processing (applying the *mediated* priming). That is, in previous *additive* priming studies (e.g. Arias-Trejo & Plunkett, 2013; Avila-Varela et al., 2021; Mani & Plunkett, 2011), a prime stimulus is followed by a phonologically or semantically associated target word. For example, the pair “door”- “dog” share the onset /d/ and belong to different categories, so they are *only* phonologically related. On the other hand, in *mediating* priming studies, although phonological and semantic links between words were activated, such activation requires two steps for recognition (e.g., Altvater-Mackensen & Mani, 2013a; Angulo-Chavira & Arias-Trejo, 2018, 2021; Mani et al., 2012). For example, in an initial stage of processing, the prime stimulus “cup” activates towards a phonological relationship a phonological associate “cat”. Then in the second stage of processing, the mediator stimuli “cat” facilitates recognising “dog”—its semantic associate. So, in an initial stage of processing phonologically related words are activated, and on a secondary stage, words related semantically are activated.

However, the influence of phonological *and* semantic overlap between words on recognition, measured in an additive priming paradigm, has not yet been researched. That is to measure the impact on target recognition of the previous presentation of a phonologically and semantically related prime word (e.g., “turkey”–“turtle”, where words share the phonemes /tɜː/ and belong to the category animal). It is essential to assess the impact of phono-semantic links on word recognition applying an additive priming paradigm as it allows studying lexical access at the same stage of processing and directly without the retrieval of mediator words.

Here, we examine the time-course of toddlers’ lexical access when primes and targets are merely phonologically related, relative to when they are both phonologically and semantically related, to examine whether the additional semantic relation between prime and target modulates the priming effect found. Such a finding would speak directly to theories arguing that word recognition involves the activation and competition of multiple candidates that overlap with the spoken input (e.g., the *Distributed Cohort Model*, Gaskell & Marslen-Wilson, 1997, 2002; the *Cohort model*, Marslen-Wilson & Welsh, 1978; Marslen-Wilson & Tyler, 1980; or *Neighborhood Activation Model*, Luce, 1986).

For instance, according to the Distributed Cohort Model (Gaskell & Marslen-Wilson, 1997, 2002), word recognition involves the simultaneous activation of multiple word candidates that overlap phonologically, semantically —or both— with the spoken input. In this model, lexical units are points in a multidimensional space, represented by a vector of phonological and semantic output nodes, which stands for words’ phonemes and meaning, respectively. Thus, as more speech signals are perceived, the model creates a “blend” of phonological and semantic nodes that search for a match for the presented word. Thus, the so-called blend in cases where primes and targets are phonologically and semantically related will find a better match to the target than in cases where primes and targets are merely phonologically related.

In the current study we expect to find evidence of phonological interference in phonological priming trials, i.e., where the prime and target are phonologically related to one another (Avila-Varela, Arias-Trejo et al., 2021; Mani & Plunkett, 2011), and given that semantic overlap typically improves recognition of related targets (Arias-Trejo & Plunkett, 2013; but see Avila-Varela et al., 2021), we expect to see reduced interference in recognition of a phono-semantically related target preceded by a related prime.

IV. Method

Participants

Data from 40 toddlers (21 females, 19 males) were included in the study. Participants were on average 21.66 months (age range = 17.03 - 26.83). An additional 12 children were tested but excluded from further analysis due to fussiness during the experiment (*n* = 5) and trial exclusion criteria (*n* = 7; see subsection "Data Processing"). The participants came from a sample of families who responded to social media announcements (using Twitter, Facebook and the recruitment section on the official [blind region] web page), printed flyers, and personal approaches to various nurseries in a middle size city in East Midlands, United Kingdom. Of the families included, 90% had one or both caregivers in full-time employment, and 80% had one caregiver who had completed college education. The main language used in the toddlers' home (and therefore heard by them) was English (and all heard another language for fewer than 2 hours a day). The Ethics Committee of the Department of Psychology approved the study before to the start of data collection.

Stimuli

Sixty-four English words were used as stimuli in the current study, of which 70.31% were reported to be familiar to children by 18 months of age according to the norms of the British Communicative Development Inventory (Oxford-CDI; Hamilton et al., 2000). Auditory stimuli were recorded by a native female English speaker from the area using infant-directed speech. Prime words were recorded in isolation and then inserted into one of three possible expressions (i.e., *"Hey!* [Prime]", *"Oh!* [Prime]*" or "Ah!* [Prime]*"*) where the word used as prime always occurred in the final position. Target words were similarly recorded in isolation and then inserted into the trial following the prime word in each condition. Auditory stimuli were subsequently processed using GoldWave software (St. John's, Newfoundland and Labrador, Canada). The images used were prototypical images depicting the target and distractor labels on a grey background and were chosen from public libraries available online. Images of the prime label were never presented to children. Images were edited using the GNU Image Manipulation Program. Experiment Builder Software was used to present the stimuli to the children.

Apparatus

Infants were seated either in a car seat or on their caregiver's lap in front of a 24´´ LCD screen with an arm-mounted Eyelink 1000 eye tracker set to a 500Hz sample rate. The screen and eye-tracker were positioned in front of the child´s visual field, approximately 60cm away from the child using the metallic arm mount. While a short video was played as the child was seated on the chair, a sticker was pasted on the participant´s forehead or cheek to give the eye tracker a reference point to localise their eye. The eyetracker was calibrated and validated using a 5-point routine[8]. The experiment started only when all points were successfully calibrated and validated. Auditory stimuli were delivered using loudspeakers placed on a table under the monitor.

Procedure and Experimental Design

At the beginning of the testing session, families were welcomed to a room equipped with toys and were given a few minutes to familiarise themselves with the environment and experimenter. Once caregivers were informed about the goal and procedure of the study, one of them signed an informed consent form, filled out a questionnaire to provide us with information as to the socio-economic status of the family and completed a checklist with the words used in the study. Then, they were taken to the eye-tracker room, where children were seated either in a car seat or on their caregivers' lap.

All caregivers were asked not to point at or repeat the names of the words presented during the study. This procedure lasted approximately forty-five minutes in total. Once the study was completed, participants were rewarded with a book and a certificate, and their caregivers received a £10 Amazon voucher. After their visit, parents were asked to complete the Oxford Communicative Development Inventory (Hamilton et al., 2000) and send it back by post, to obtain a measure of the children's receptive and productive vocabulary size. Overall, participants' receptive size was *M* = 330 (99 – 415) words, and their productive vocabulary size was *M* = 248 (23 - 415) words.

Conditions and Counterbalancing

During the eye-tracking study, participants were presented with phonologically related trials (*Phon-Rel*), phonologically and semantically related trials (*PhonSem-Rel*) and unrelated trials (*Phon-Unrel* and *PhonSem-Unrel*). In the *Phon-Rel* trials, we defined the phonological relationship between "prime"- "target" as words that shared the initial phonemes (C or CV) and did not belong to the same superordinate category, nor were they visually similar. For example, "toe"-"toast" shares the initial CV phonemes /təʊ/. For a similar approach, see Avila-Varela, Arias-Trejo et al., (2021). The *PhonSem-Rel* trials were formed by words that shared the initial phonemes and were exemplars from the same superordinate category. For example, "rat"-"rabbit" shares the initial phonemes /ræ/ and belong to the category "animals".

For the unrelated trials, the same targets and primes as in the related trials were used but pairing each prime word with a target that did not overlap either phonologically or semantically with it. For example, "bubble"-"toast" in the *Phon-Unrel* condition; and "salt"-"rabbit" for the *PhonSem-Unrel* condition. Thus, the *Phon-Unrel* trials presented participants with the same primes and target words used in phonologically related trials, only guaranteeing that the primes and target were now mixed so that there was no phonological or semantic relationship between the two. Similarly, in the PhonSem-Unrel trials, participants were presented with the primes and target presented in phono-semantically related trials but now mixed to ensure no relationship between the two. Table 6 presents a complete list of the word pairs used in the study.

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[8] Two participants were mistakenly presented with the screen in a different resolution for which a 3-point calibration procedure was used.

Table 6

Phonological and phono-semantic pairs of words by related and unrelated conditions

Phonological Link

Unrelated Label	Prime Label	Target Picture	Distractor Picture
bubble	toe	toast	chair
/bʌbəl/	/təʊ/	/təʊst/	/tʃeər/
jam	boat	bowl	cow
/dʒæm/	/bəʊt/	/bəʊl/	/kaʊ/
boat	jam	jacket	teddy
/bəʊt/	/dʒæm/	/dʒækɪt/	/tedi/
soap	butter	bus	nappy
/səʊp/	/bʌtər/	/bʌs/	/næpi/
butter	soap	sofa	hat
/bʌtər/	/səʊp/	/səʊfə/	/hæt/
toe	bubble	button	spoon
/təʊ/	/bʌbəl/	/bʌtən/	/spu:n/
plate	balloon	banana	elephant
/pleɪt/	/bælən/	/bənɑ:nə/	/elɪfənt/
balloon	plate	plane	eye
/bəlu:n/	/pleɪt/	/pleɪn/	/aɪ/

Phono-semantic Link

Unrelated Label	Prime Label	Target Picture	Distractor Picture
salt	rat	rabbit	trousers
/sɒlt/	/ræt/	/ræbɪt/	/traʊzəz/
tummy	pizza	peas	book
/tʌmi/	/pi:tsə/	/pi:/	/bʊk/
pizza	tummy	tongue	car
/pi:tsə/	/tʌmi/	/tʌŋ/	/kɑ:r/
turkey	box	bottle	apple
/tɜ:ki/	/bɒks/	/bɒtəl/	/æpəl/
rat	salt	sausage	table
/ræt/	/sɒlt/	/sɒsɪdʒ/	/teɪbəl/
camel	salad	sandwich	finger
/kæməl/	/sæləd/	/sænwɪdʒ/	/fɪŋgər/
salad	camel	cat	shoe
/sæləd/	/kæməl/	/kæt/	/ʃu:/
box	turkey	turtle	glasses
/bɒks/	/tɜ:ki/	/tɜ:təl/	/glæsəz/

Note: International Phonetic Alphabet transcriptions are presented between slashes.

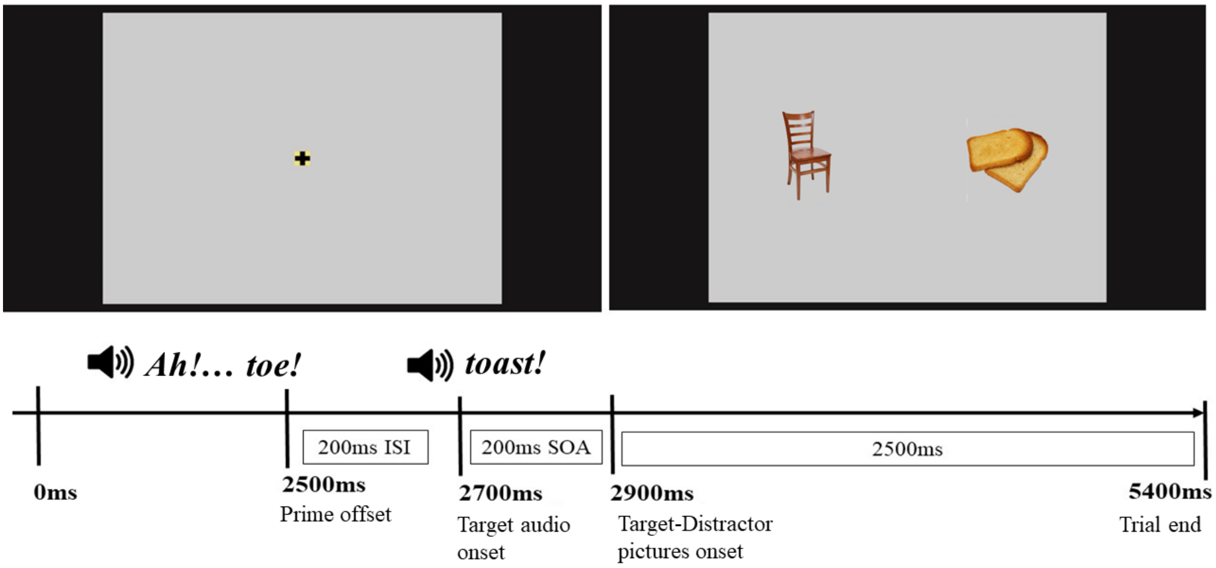
Participants were presented with a total of sixteen trials, four for each type (Phon-Rel/Unrel, PhonSem-Rel/Unrel). The words used appeared uniquely in one of the overlaps studied here, either in the phonological (i.e., Phon-Rel/PhonUnrel trials) or phono-semantic (i.e., PhonSem-Rel/Unrel trials). In addition, each label and image appeared only once within the study for each participant. Across participants, words were counterbalanced such that primes and target-distractor pairs appeared equally often in the related and unrelated conditions (within phonological or phono-semantic lexical links). We followed a within-subject design for the trial presentation, where trials appeared in a pseudo-random order, with no more than two consecutive trials of the same condition. Also, the side of the target picture presentation (left-right) was counterbalanced across participants. The experimenter manually started each trial once the child fixated on the attention-getter.

Trial structure

We used an adaptation of the IPL paradigm similar to Arias-Trejo and Plunkett (2013) combined with eye tracking. After the child fixated on the attention-getter, the trial began with the carrier phrase containing the prime stimulus combined with the display on the screen of a centrally located black fixation cross. The prime label offset was timed at 2500ms from the trial onset. The target label was presented following an interstimulus interval of 200ms (i.e., 2700ms into the trial). The target and distractor pictures appeared following a stimulus onset asynchrony of 200ms (i.e., 2900ms into the trial) and remained on screen for 2500ms. Thus, the total duration of each trial was 5400ms (see Figure 10).

Figure 10

Trial stimuli sequence presentation.



Note. ISI, interstimulus interval; SOA, stimulus onset asynchrony.

Statistical Analysis

Data Processing

A custom code written in R (R Core Team, 2013) was used to process the gaze data exported from the eye tracker. Eye movement coordinates were recorded at 500Hz (with one data-point every 2ms) and binned into 40ms intervals offline for plotting and analysis. Only data reliably collected during picture presentation (i.e., 2900ms to 5400ms on trial) were included. Areas of interest (AOI) on the screen were defined according to the size of the target and distractor images (i.e., 300 by 300 pixels) plus a frame of 60 pixels (up, down, left, and right sides, i.e., 420 by 420 pixels).

The pictures were positioned at 120 pixels from the monitor´s top and with 660 pixels between pictures on the full-screen modality presentation and 362 pixels from the top of the monitor, and 340 pixels of separation between pictures in the small modality presentation.

Exclusion Criteria

We applied three trial exclusion criteria. First, we removed trials in which infants fixated the images less than 20% of the time window for analysis (240-2000ms from pictures onset, i.e., 352ms). This criterion was implemented to eliminate trials where participants were not focused on the task (see Borovsky et al., 2016c, for a similar approach). From the remaining set of trials, we removed the trials where participants fixated only one image. The rationale for this criterion was to ensure that we removed any trials where fixations may have been driven solely by children's visual preferences for one of the two displayed pictures (see Avila-Varela, Arias-Trejo et al., 2021; Mani et al., 2012; Mani & Plunkett, 2011). Thirdly, after applying these criteria, we discarded the data of *seven* participants for their failure to provide at least one trial in all conditions. In summary, we maintained 66.98% of all the trials (n = 428). Specifically, in the *Phon-Rel* condition we included 69.38% of the trials (n = 111), in the *Phon-Unrel* condition we included 70.62% of the trials (n = 113), in the *PhoSem-Rel* condition we included 66.67% of the trials (n = 106), and in the *PhoSem-Unrel* condition we included 61.25% of the trials (n = 98).

The Dependent Variable

Our dependent variable is the proportion of target looking (PTL) calculated across the entire time-course of the trial and for each time-bin in the trial. This captures the proportion of time that participants spent fixating the target relative to the time spent fixating the target and distractor. For statistical analysis, we only included data from 240ms to 2000ms after the onset of the pictures (3160 - 4880ms in the trial) to ensure that fixations that could reasonably be considered a response to stimulus presentation were included (Fernald et al., 1998).

Statistical Models

All analyses were carried out with linear mixed-effects modelling (LMEM) using the lme4 package (version 1.1-26; Bates et al., 2015) in RStudio (version 1.1.463; and R version, 4.0.5) with the proportion of target looking as the dependent variable calculated across the time window of 240 to 2000ms following image onset in each trial. The models' lmer outputs and covariance matrices are reported in the Appendixes. The levels of categorical conditions were assigned contrast codes as follows, condition (unrelated/related as 1/-1) and lexical link type (phonological/phono-semantic as 1/-1). In addition, contrast levels were sum-coded so that the interactions in the model refer to the contrast across conditions or the lexical link type studied.

Statistical significance (*p*-values) for individual parameter estimates were assessed using the normal approximation (i.e., treating the *t*-value as a *z*-value).

In all models, collinearity between variables was checked using the measures kappa (κ) and the variance inflation factor (VIF) from the regression-utils.r and mer-utils.r functions (Frank & O'Hora, 2014, retrieved from GitHub). Thresholds on $\kappa > 15$ and $VIF > 10$ are considered indicators of the independent variables being highly correlated (e.g., see Tomaschek et al., 2018)[9]. The data and analysis scripts are available on the Open Science Framework at https://osf.io/dga3c/?view_only=cd9cf1a40f4c4ab08130237e152138ea (Avila-Varela, Jones & Mani, 2022).

We report planned analyses examining the overall effect of condition and lexical link type on target, applying a generalized linear mixed-effects model (GLM). In addition, and to assess changes in the curves for target looking across the trial, we executed a growth curve analysis (GCA, Mirman, 2017). Finally, we carried out GLM models for each lexical link separately (*Phon-Rel* and *Phon-Unrel* trials on the one hand, and *PhonSem-Rel* and *PhonSem-Unrel* on the other) explore whether target looking was explained by the prime-target relatedness within lexical link type. Thus, these analyses were carried out to determine the presence of phonological and phono-semantic priming effects.

Further Details about the GCA

We analysed the eye tracking data using mixed-effects growth curve analyses (Mirman, 2017) with the proportion of target looking (PTL) in each time bin as the dependent variable. This statistical analysis was also carried out in R using the lme4 package (version 1.1-26; Bates et al., 2015) to calculate two-level mixed-effects growth curve models with full information maximum likelihood estimation. The model compared PTL on each condition (related vs unrelated) and lexical link type (phonological vs phono-semantic) at the intercept, linear, quadratic, and cubic temporal terms. PTL across the 44-time bins were used as base model observations. The rationale for modelling the linear, quadratic and cubic temporal terms was to estimate the slope, acceleration, and inflexions in the extremities of the target looking curves across the trial. We used orthogonal polynomial transformations for the time bins at the linear, quadratic and cubic terms to ensure that time on trial was orthogonal to each other and that the correlations between time elevated to the different exponentials do not arise due to the mere increase in the numbering. We included as random effects: participants by condition, target label by condition, lexical link type by condition, and condition by lexical link type. The random effects were nested within the linear and quadratic temporal terms to capture the variance associated with each participant at the acceleration and central inflexions on target recognition through the trial. In this case, statistical significance (*p*-values) for individual parameter estimates were also assessed using the normal approximation (i.e., treating the *t*-value as a *z*-value).

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[9] Deviations from accepted norms in either of these measures ($\kappa > 10$ and $VIF > 3$) are reported. Covariance matrices show values lower than zero.

IV. Results

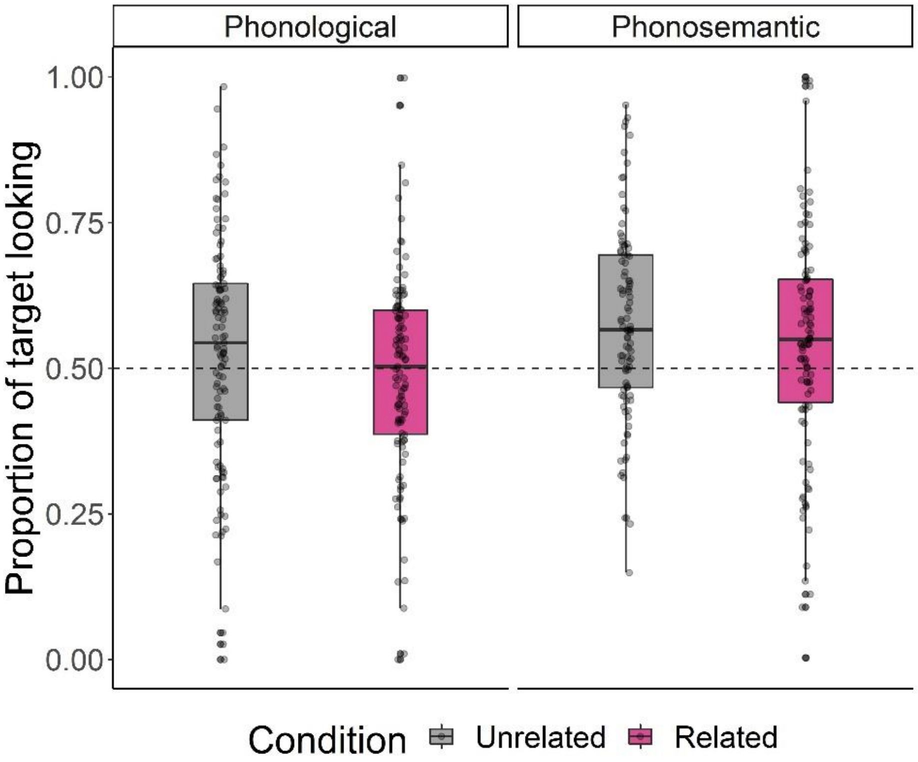
Overall Target Looking

First, we ran a generalised mixed-effect model to evaluate the overall effect of *condition* and *lexical link type* on target looking across trials. In the model, PTL was the dependent variable, and we included the fixed effects and interaction of condition and lexical link type (κ = 1.13 and *VIF* = 1.03). Those values of κ and VIF below ten are considered indicators of the independent variables not being correlated to each other (Tomaschek et al., 2018). The model syntax was: lmer(ptl ~ condSum*typeSum + (1+condSum*typeSum | subject) + (1+condSum | target) + (1+condSum | typeSum) + (1+typeSum | condSum), data=uk.aggr.red_corr, REML=FALSE, control = contr).

Figure 11 depicts participants total target looking in phonologically and phono-semantically related and unrelated trials. The parameter estimates from this model highlighted the significant effect of *lexical link type*, estimate = -0.03, *p* = .04 (see Appendix M for model output and covariance matrix). This result indicates differences in total target looking in phonological (related and unrelated) and phono-semantic (related and unrelated) trials. As seen in Figure 11, children looked more at the target image in the phono-semantically related and unrelated trials (*M* = 0.56, *SE* = 0.01.) than in the phonologically related and unrelated trials (*M* = 0.51, *SE* = 0.01). This result, combined with the overall impression of target looking being higher in the phono-semantically related condition than in the phonologically alone related condition, suggest an improved target recognition in the combined overlap condition than in the single overlap condition. However, we do not find a main effect of condition (related vs unrelated trials) (*p* >.05), thus suggesting no evidence of priming effects on word recognition when considering the total looking times.

Figure 11

Total target looking time proportions in phonologically and phono-semantically trials.



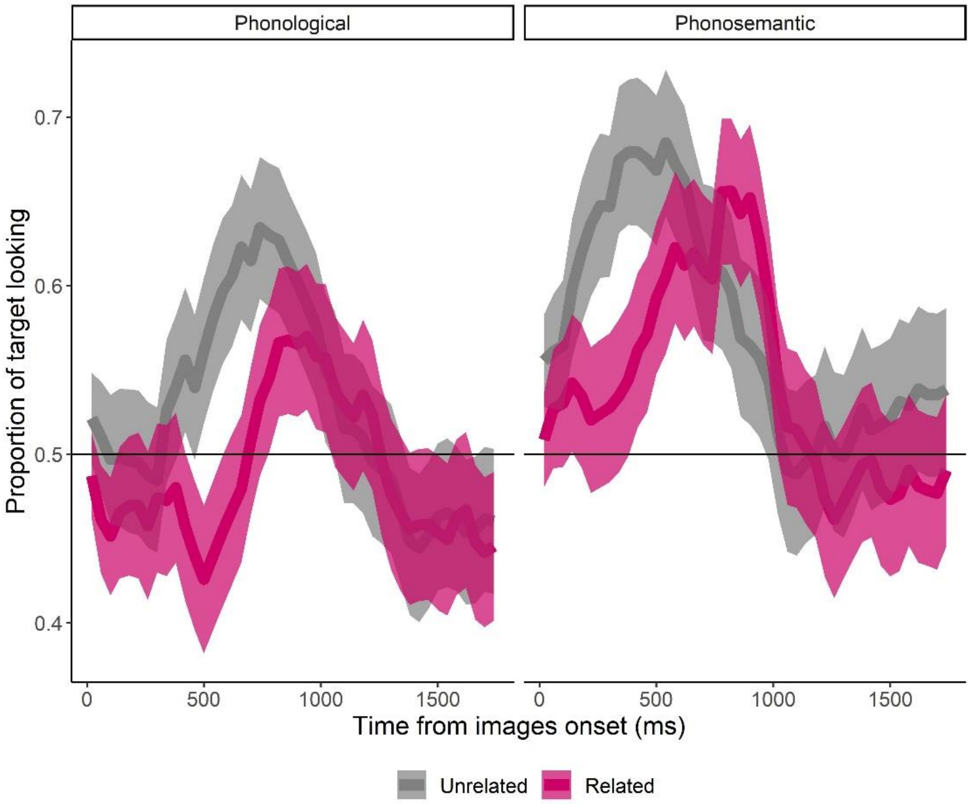
Note. The left panel has proportions of target looking in phonologically related (dark pink) and unrelated (grey) trials. The right panel has proportions of target looking in phono-semantically related (dark pink) and unrelated (grey) trials. Dots represent participant means of target looking.

Secondly, we carried out a growth curve analysis to examine the changes in target looking throughout the trial. This model included the fixed effects and interaction of condition and lexical link type, at the intercept, linear, quadratic, and cubic temporal terms (κ = 1.13 and *VIF* = 1.24). The values of κ and VIF below 10 indicate that the independent variables were not highly correlated to each other (Tomaschek et al., 2018). The model syntax was: lmer(ptl ~ (poly1+poly2+poly3)*condSum*typeSum + (poly1+poly2 || subject:condSum) + (poly1+poly2 | target:condSum) + (poly1+poly2 | typeSum:condSum) + (poly1+poly2 | condSum:typeSum), data=uk.red.gca, REML=FALSE, control = contr).

See Appendix N for the model output and covariance matrix. In what follows, we shall only comment on the significant effects regarding the variables of interest (i.e., condition and lexical link type). Model parameter estimates showed a significant effect of *lexical link type at the intercept*, estimate = -0.03, *p* = .01, indicating an overall difference in target looking in phonological and phono-semantic trials. Also, the model also showed a significant interaction between *lexical link type* and the *cubic temporal term* (estimate = -0.07, *p* < .001), pointing towards differences in the inflexions at the extremities of target looking curves in phonological and phono-semantic trials (see Figure 12). Finally, the model also revealed a significant interaction between the *condition* by the *cubic temporal term* (estimate = 0.08, *p* < .001), suggesting differences in the inflexions at the extremities of target looking curves in related and unrelated trials (see Figure 12). Overall, these results show fine-grained evidence of priming effects relating to interference in the phonological and phono-semantic conditions towards interference in target recognition.

Figure 12

Time-course of target fixations in phonologically and phono-semantic trials.



Note. The left panel depicts target fixations' time-course in phonologically related (dark pink) and unrelated (grey) trials. The right panel depicts target fixations' time-course in phono-semantically related (dark pink) and unrelated (grey) trials. Lines represent the mean, and ribbons represent SE.

Phonological Lexical Link

In order to further examine phonological priming effects, we then ran a generalised mixed-effect model of total looking times, where we included the effect of condition across only phonologically related and unrelated trials (with κ = 1.01 and *VIF* = 1.00, indicating a low correlation between factors). The model syntax was: lmer(ptl ~ condSum + (1+condSum | subject) + (1+condSum | target), data=subset(uk.aggr.red_corr, uk.aggr.red_corr$type=="Phon"), REML=FALSE, control = contr). See Appendix O for the model output and covariance matrix. This model parameter estimates with phonologically related and unrelated trials showed no significant effect of condition, estimate = 0.02, *p* = .17. This result suggests that when considering differences in total looking, there is no evidence of phonological priming effects in target recognition. Although Figures 11 and 12 may suggest that children show phonological interference, that is, that participants looked more to the target in unrelated trials (*M* = 0.53, *SE* = 0.02) than in related trials (*M* = 0.49, *SE* = 0.02), this difference was not statistically significant when looking at the total looking times collapsed across the full-time window for analysis.

Additionally, we carried out GCA to analyse fixations curves changes as time progressed on phonologically related and unrelated trials. The GCA model syntax is: lmer(ptl ~ (poly1+poly2+poly3)*condSum + (poly1+poly2|| subject:condSum) + (poly1+poly2| target:condSum), data=subset(uk.red.gca, uk.red.gca$type=="Phon"), REML=FALSE, control = contr). This model (κ = 1.01 and *VIF* = 1.10) found a significant interaction between *condition* and the *cubic temporal term* (estimate = 0.09, p < .001). See Appendix P for the full model output. The results in this fine-grained analysis found significant differences in target looking curves initial inflexions when comparing the target looking in the related and unrelated trials. As suggested in Figure 12, target looking was more accurate during the first second after images prompt on screen in phonologically unrelated trials than phonologically related ones. In sum, the results in the growth curve analyses highlight a phonological interference in word recognition.

Phono-Semantic Lexical Link

Similarly, to evaluate phono-semantic priming effects, we ran a GLM model on aggregated looking times, in which we included the effect of condition across only phono-semantically related and unrelated trials (with κ = 1.06 and *VIF* = 1.00, indicating a low correlation between factors). Model syntax: lmer(ptl ~ condSum + (1+condSum | subject) + (1+condSum | target), data=subset(uk.aggr.red_corr, uk.aggr.red_corr$type=="PhonSem"), REML=FALSE, control = contr). This model´s parameter estimates showed no significant effect of condition (estimate = 0.01, p = .35), which suggests no evidence of phono-semantic priming effects in target recognition when considering total looking times (see Appendix Q for the model, output, and covariance matrix). Although Figures 11 and 12 may insinuate phono-semantic interference, that is higher target looking in unrelated trials (*M* = 0.57, *SE* = 0.02) than in related trials (*M* = 0.54, *SE* = 0.02), this difference was not statistically significant in the GLM.

Analogous to the analyses in the phonological overlap, we carried out GCA to analyse fixations curves changes as time progressed on phono-semantic related and unrelated trials. The GCA model syntax is: lmer(ptl ~ (poly1+poly2+poly3)*condSum + (poly1+poly2|| subject:condSum) + (poly1+poly2| target:condSum), data=subset(uk.red.gca, uk.red.gca$type=="PhonSem"), REML=FALSE, control = contr). See Appendix R for the full model output. This model (κ = 1.06 and *VIF* = 1.19) show the significant main effect of the *cubic temporal term*, indicating an overall initial inflexion on target fixation in both related and unrelated trials. However, the model also reveals a significant interaction between *condition* and the *cubic temporal term* (estimate = 0.06, p < .001). Thus, the results in this fine-grained analysis suggest priming effects in target recognition towards an interference effect, indicated by the initial higher target looking in the phono-semantically unrelated than in the related condition (see Figure 12).

IV. Discussion

The current study aimed to compare phonological and phono-semantic overlap effects on word recognition applying the additive priming paradigm. Overall, the analyses of total looking times and target looking curves (with all trials) found a significant main effect of lexical link type, with higher target looking in the phono-semantic trials than in phonological trials. Thus, indicating better target recognition in phono-semantic trials(related/unrelated) than in phonological trials (related/unrelated). Indicating, that in the phono-semantic condition, there was more looking generally, regardless of priming. In addition, the growth curve analyses found a significant interaction between condition and the cubic temporal, suggesting differences in target looking curves in related versus unrelated trials, with an advantage in target recognition in unrelated trials (i.e., interference regardless of the type of prime).

However, it is important to note that when considering all trials (i.e., PhoRel, PhoUnrel, PhoSemRel y PhoSemUnrel), we do not find a significant interaction between condition and lexical link type across analyses (total looking times and curves of target looking). Therefore, there is no robust evidence of differences between the Phonological and Phono-semantic interference effects.

Finally, additional analyses in phonological and phono-semantic trials separately do not find evidence to support the presence of phonological or phono-semantic priming effects when considering total looking data. In contrast, analyses of target looking curves changes do provide evidence of phonological and phono-semantic priming effects, whit higher target looking's in the unrelated conditions on the first second after images' display. These results indicate phonological and phono-semantic interference effects in target looking when assessing changes in time course of fixations.[10]

These differences in the results might be due to the type of analysis carried out and on the changes that they can explain. The generalised mixed-effect model (GLM) is done on total proportions of looking time aggregated from the whole time window after images onset. Thus, the GLM analyses inform about vast differences in total proportions of target looking across conditions. In this case, higher proportions of target looking at the start of the time window can be cancelled out by lower proportions at the end. In contrast, growth curve analysis (GCA) examines subtle changes in target looking curves across a given time window. Thus, this method tells when there was a difference in target fixations curves across conditions within the time window for analyses.

The phonological and phono-semantic interference effects (i.e., that is better target recognition when preceded by an unrelated than by a related prime), will be explained by models of spoken word recognition that suggest a competition mechanism underlying speech processing (e.g., *Cohort Model*, Marslen-Wilson & Welsh, 1978; Marslen-Wilson & Tyler, 1980; or *Neighborhood Activation Model*, Luce, 1986). According to these models upon hearing a word, phonologically related words are activated and compete for recognition generating interference effects in word recognition.

In addition, the relative lower interference in target recognition in phono-semantic trials (in comparison to the phonological trials) suggested in Fig. 13 can be accounted for in the context

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[10] A separate analysis including all trials provided by the final sample (N = 40) showed a similar pattern of results, except for the GLM model carried out with all data where no significant effect of lexical link type was found and in the GCA with the phono-semantic trials, where no significant interaction between condition and the cubic temporal term was found. Further analysis with trials where participants were familiar with all words (N = 35) showed similar results. In this case, we lost additional participants due to missing vocabulary data. With this subset of trials, the GLM and GCA models with all data did not show significant effects of lexical link type,

Moreover, no significant interaction between condition and the cubic temporal term was found in the GCA with phonological trials. For more details, please visit the OSF site https://osf.io/dga3c/?view_only=cd9cf1a40f4c4ab08130237e152138ea of the Distributed Cohort Model (Gaskell & Marslen-Wilson, 1997). According to it, the word recognition system maps speech into phonological and semantic information upon hearing it. Here, lexical units are points in a multidimensional space, represented by phonological and semantic output nodes vectors. The phonological nodes comprise information about the phonemes in a word, and the semantic nodes comprise the meaning of the words. As more speech input is processed, the network moves toward a point in the lexical space corresponding to the presented word. Here, selecting the right word for recognition occurs when their activation increases relative to other plausible candidates. The Distributed Cohort Model can clarify the lower interference effects in the phono-semantic trials (relative to phonological trials), as the added semantic overlap between words might had increase the distributed activation of the also semantically related candidates among all the phonologically related candidates. Thus, the added sematic overlap might had narrowed down the number plausible words candidate for recognition.

In what follows, we discuss the current results in light of previous research. Regarding the phonological lexical link, we found that children showed no priming or interference effect in the total looking times analyses. However, the growth curve analyses highlight initial ease to recognize the target in unrelated relative to related trials. The GCA results of phonological interference effects match with previous results founding that phonological interference at 24 months of age (Mani & Plunkett, 2011) and with children with larger receptive vocabulary size (Avila-Varela et al., 2021).

However, research with younger participants of 18 months of age reports phonological priming effects (Mani & Plunkett, 2010a). The differences between our results of early phonological interference effects (as shown by the GCA) and the phonological facilitator priming effects reported in Mani & Plunkett (2010a) might be due to the difference in age of the participants tested and the associated differences in receptive vocabulary size. The 18-month-old participants tested in Mani and collaborators (2010a) study might have a reduced vocabulary and therefore counted with fewer competitors for recognition during the task. In contrast, the 22-month-old participants tested in the current study might have had a more extensive vocabulary size with that may lead to activating more phonologically related words and leading to interference in word recognition.

Regarding the phono-semantic lexical link, our results show a trend towards phono-semantic interference (only in the GCA); similar findings are reported in studies where backward semantic inhibition effects on word recognition are found (Chow et al., 2016, 2018). In Chow and collaborators´ (2016,2018) study, an intervening stimulus between the prime and the target is presented, and it could be either a word (labelled and accompanied by its image) or a tone (accompanied by the image of a checkerboard). Next, the target and distractor images side-by-side are presented, and the target label is named. For example, for the semantic related “chair” – “table”, and unrelated pair “coat” – “table”, the intervening stimulus is the word “chicken” or a tone. Applying this paradigm was found that 24-month-old toddlers looked more at the target (e.g., “table”) in the semantically related condition (than in the unrelated condition, i.e., facilitation effect) when the intervening stimulus was a tone. While, target recognition was higher in the unrelated than in the semantically related condition (i.e., interference effect) when the intervening stimulus was a word. Under this paradigm, the semantic inhibition occurs when the intervening stimulus is a word (and not when it is a tone) because requires lexical processing and thus breaks the processing of the semantic relationship between the prime and the target.

In addition, a more recent study found that those backward semantic interference effects were replicated in younger infants of 18 months of age with higher vocabulary (Chow et al., 2019). The authors found that in a sample of 18-month-old children, those with higher vocabulary looked more at the target in unrelated trials than in the semantically related trials when the intervening stimulus was a word (i.e., showing backward semantic inhibition effects on word recognition). Those results indicate that inhibitory processes are closely related to vocabulary growth. As suggested by the authors, as the number of lexical items increases, the need to develop an adult-like word recognition system organized upon activation and inhibition links between words also increase.

Contrary to our results of phono-semantic interference effects, previous research applying the mediated priming paradigm found priming effects, i.e., better recognition when previously related words were presented. Specifically, previous research found forward phonological to semantic priming effects at 24 and 30 months of age (Angulo-Chavira & Arias-Trejo, 2018; Mani et al., 2013); and semantic to phonological priming at 30 months of age (Angulo-Chavira & Arias-Trejo, 2018). These contradictory results may be due to the different experimental designs implemented, i.e., applying the *mediated* (Angulo-Chavira & Arias-Trejo, 2018; Mani et al., 2012) or the *additive* priming paradigm in the current study. The *mediated* priming designs require the participant to access the phonological and semantic lexical cues in sequential stages of processing that may dilute interference effects driven by shared phonological features between words. While, in the *additive priming* paradigm, the prime and target are presented in quick succession, so phonologically and phono-semantically associated words are activated simultaneously, at the same phase of processing.

Another plausible reason why we did not find phonological or phono-semantic priming effects with the total looking analysis may have been because we presented each participant with a higher proportion of unrelated trials (50%) than related trials in each lexical link (25%). This may have increased the difficulty for children to notice the lexical links tested here (see Arias-Trejo et al., 2021; for a similar reasoning).

Further research aiming to test the effect of phonological and phono-semantic related pairs of words on early word recognition should address and aim to overcome the limitations presented in the current study. Firstly, it would be advisable for authors to balance the proportion of high and low cohort size labels presented across priming conditions, as previous research with toddlers has found cohort effects on word recognition (Mani & Plunkett, 2011). Secondly, we recommend that future studies test participants older than 21 months of age (ideally of 24 or 30 months of age), since previous research has found phonological interference effects (Mani & Plunkett, 2011), semantic priming (Arias-Trejo & Plunkett, 2013; Styles & Plunkett, 2009, 2011), and phono-sematic mediated priming effects (Angulo-Chavira & Arias-Trejo, 2018; Mani et al., 2012) around this age bracket. Furthermore, future research might benefit from implementing a between-subjects design, which would allow participants to receive the same proportion of related and unrelated trials.

IV. Conclusions

The current study suggests that adding semantic information to phonologically related pairs of words reduces interference effects in spoken word recognition in early childhood, as shown in changes on fixations curves as time in the trial progress. Thus our results indicate that the recognition system of 21-month-old children can be benefited from semantic cues to support spoken word recognition when the phonological overlap is also at play.

IV. Acknowledgements

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IV. Author Contributions

D.S.A-V. and N.M. developed the concept for the study, G.J. contributed to the improvement of the study design. D.S.A-V and Francesco Cabiddu performed testing and data collection. Data analysis was performed by D.S.A-V. and N.M. The manuscript was written by D.S.A-V. and was edited by N.M. and G.J. All authors approved the final version of the manuscript for submission.

IV. Appendix M

Output of the generalized linear model including the fixed effects of condition and lexical link type on target looking

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	0.53	0.01	37.76	0.00***
Condition (unrelated vs. related)	0.01	0.01	1.61	0.10
Lexical link (phonological vs. phono-semantic)	-0.03	0.01	-2.00	0.04*
Condition by type	0.00	0.01	0.00	0.99

Signif. codes: 0.001 '***' 0.05 '*'

Covariance Matrix

	Int.	Cond.	Type	Cond. by Type
Int.	2e-04	0e+00	0e+00	0e+00
Cond.	0e+00	1e-04	0e+00	0e+00
Type	0e+00	0e+00	2e-04	0e+00
Cond. by type	0e+00	0e+00	0e+00	1e-04

Note. Int, intercept; Cond, condition; Type, lexical link type.

IV. Appendix N

Output of the growth curve model including the fixed effects of condition and lexical link type on target looking

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	0.53	0.02	33.59	0.00***
Linear term	-0.12	0.17	-0.69	0.49
Quadratic term	-0.15	0.09	-1.62	0.10
Cubic term	0.11	0.02	5.53	0.00***
Condition (intercept)	0.02	0.02	1.04	0.30
Type (intercept)	-0.03	0.01	-2.46	0.01*
Linear term by condition	-0.04	0.17	-0.28	0.77
Quadratic term by condition	0.02	0.10	0.20	0.84
Cubic term by condition	0.08	0.02	4.03	0.00***
Linear term by type	0.04	0.13	0.31	0.76
Quadratic term by type	-0.03	0.08	-0.49	0.63
Cubic term by type	-0.10	0.02	-4.99	0.00***
Condition by type (intercept)	0.00	0.01	-0.12	0.90
Linear term by condition by type	-0.09	0.14	-0.63	0.53
Quadratic term by condition by type	-0.07	0.08	-0.93	0.35
Cubic term by condition by type	0.01	0.02	0.70	0.48

Signif. codes: 0.001 '***' 0.05 '*'

Covariance Matrix

	Int.	Lin.	Quad.	Cub.	Cond.	Type	Lin. by Cond.	Quad. by Cond.	Cub. by Cond.
Int.	0.000255	-0.000102	-0.000445	0	0	-1.00E-06	0	0	0
Lin.	-0.000102	0.028663	-8.00E-05	0	0	0	1.30E-05	0	0
Quad.	-0.000445	-8.00E-05	0.009169	0	0	0	0	1.20E-05	0
Cub.	0	0	0	0.000381	0	0	0	0	5.00E-06
Cond.	0	0	0	0	0.000255	0	-0.000102	-0.000445	0
Type	-1.00E-06	0	0	0	0	0.000168	0	0	0
Lin. by Cond.	0	1.30E-05	0	0	-0.000102	0	0.028663	-8.00E-05	0
Quad. by Cond.	0	0	1.20E-05	0	-0.000445	0	-8.00E-05	0.009169	0
Cub. by Cond.	0	0	0	5.00E-06	0	0	0	0	0.000381
Lin. by Type	0	-2.40E-05	0	0	0	-0.000102	-2.20E-05	0	0
Quad. by Type	0	0	-2.40E-05	0	0	-0.000445	0	-2.10E-05	0
Cub. by Type	0	0	0	-1.70E-05	0	0	0	0	-8.00E-06
Cond. by Type (int.)	0	0	0	0	-1.00E-06	0	0	0	0
Lin. by Cond. by Type	0	-2.20E-05	0	0	0	0	-2.40E-05	0	0
Quad. by Cond. by Type	0	0	-2.10E-05	0	0	0	0	-2.40E-05	0
Cub. by Cond. by Type	0	0	0	-8.00E-06	0	0	0	0	-1.70E-05

Note. Int, intercept; Lin, linear temporal term; Quad, quadratic temporal term; Cub, cubic temporal term; Cond, condition; Type, lexical link type.

Covariance Matrix (continuation)

	Lin. by Type	Quad. by Type	Cub. by Type	Cond. by Type (int.)	Lin. by Cond. by Type	Quad. by Cond. by Type	Cub. by Cond. by Type
Int.	0	0	0	0	0	0	0
Lin.	-2.40E-05	0	0	0	-2.20E-05	0	0
Quad.	0	-2.40E-05	0	0	0	-2.10E-05	0
Cub.	0	0	-1.70E-05	0	0	0	-8.00E-06
Cond.	0	0	0	-1.00E-06	0	0	0
Type	-0.000102	-0.000445	0	0	0	0	0
Lin. by Cond.	-2.20E-05	0	0	0	-2.40E-05	0	0
Quad. by Cond.	0	-2.10E-05	0	0	0	-2.40E-05	0
Cub. by Cond.	0	0	-8.00E-06	0	0	0	-1.70E-05
Lin. by Type	0.018605	-8.00E-05	0	0	1.20E-05	0	0
Quad. by Type	-8.00E-05	0.005954	0	0	0	1.10E-05	0
Cub. by Type	0	0	0.000381	0	0	0	5.00E-06
Cond. by Type (int.)	0	0	0	0.000168	-0.000102	-0.000445	0
Lin. by Cond. by Type	1.20E-05	0	0	-0.000102	0.018605	-8.00E-05	0
Quad. by Cond. by Type	0	1.10E-05	0	-0.000445	-8.00E-05	0.005954	0
Cub. by Cond. by Type	0	0	5.00E-06	0	0	0	0.000381

Note. Int, intercept; Lin, linear temporal term; Quad, quadratic temporal term; Cub, cubic temporal term; Cond, condition; Type, lexical link type.

IV. Appendix O

Output of the generalized linear model including the fixed effect of condition on target looking on phonologically related and unrelated trials

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	0.50	0.01	34.99	0.00***
Condition	0.02	0.01	1.35	0.17

Signif. codes: 0.001 '***'

Covariance Matrix

	Int.	Cond.
Int.	2e-04	0e+00
Cond.	0e+00	2e-04

Note. Int, intercept; Cond, condition.

IV. Appendix P

Output of the growth curve model including the fixed effect of condition on target looking on phonologically related and unrelated trials

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	0.50	0.02	28.98	0.00***
Linear term	-0.05	0.21	-0.26	0.79
Quadratic term	-0.19	0.14	-1.35	0.18
Cubic term	0.01	0.02	0.41	0.68
Condition (intercept)	0.01	0.02	0.81	0.42
Linear term by condition	-0.13	0.21	-0.65	0.51
Quadratic term by condition	-0.05	0.14	-0.36	0.71
Cubic term by condition	0.09	0.02	3.63	0.00***

Signif. codes: 0.001 '***' 0.05 '*'

IV. Appendix Q

Output of the generalized linear model including the fixed effect of condition on target looking on phono-semantically related and unrelated trials

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	0.56	0.02	22.88	0.00***
Condition	0.02	0.02	0.95	0.34

Signif. codes: 0.001 '***'

Covariance Matrix

	Int.	Cond.
Int.	6e-04	-1e-04
Cond.	-1e-04	3e-04

Note. Int, intercept; Cond, condition.

IV. Appendix R

Output of the growth curve model including the fixed effect of condition on target looking on phono-semantically related and unrelated trials

	Estimate	SE	*t*-value	*p*(>|t|)
Intercept	0.57	0.02	22.12	0.00***
Linear term	-0.14	0.24	-0.57	0.57
Quadratic term	-0.16	0.14	-1.18	0.24
Cubic term	0.20	0.03	7.78	0.00***
Condition (intercept)	0.02	0.02	0.78	0.43
Linear term by condition	0.10	0.24	0.41	0.68
Quadratic term by condition	0.11	0.14	0.80	0.42
Cubic term by condition	0.06	0.03	2.47	0.01*

Signif. codes: 0.001 '***' 0.05 '*'

Chapter V. Avila-Varela, Hartmann & Mani (2022)

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Effects of Words' Phonological and Semantic Overlap in Novel Word Recognition

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V. Abstract

Young children encode similarities among novel labels and referents. However, less is known about the role of phonological and semantic overlap between novel labels and their referents on word learning. Hence, in this study, we applied a between-subjects design, where N = 104 (50 females) 22-month-old toddlers were taught two novel label-referent associations. A *phonologically* related condition, where novel labels shared the initial syllable (/simi/ and /sinqa/, here /si/), and the referents belonged to a different category (food and musical instrument). A *semantically* related condition, where labels sounded different (/simi/ and /alku/) and referents belonged to the same category (food). A *phono-semantically* related condition, where labels sound-alike (/simi/ and /sinqa/) and referents belong to the same category (food). Finally, an *unrelated* condition, where labels were phonologically dissimilar (/simi/ and /alku/) and their referents belonged to different categories (food and musical instrument). Novel target recognition was measured in a preferential-looking task, where an Eye-Tracker recorded participants' fixations. Total-looking-time and time-course analyses were carried out, while the former analyses did not show significant differences across conditions; time-course analyses revealed accurate novel target recognition in the *phonologically* and *semantic* related conditions compared with the *phono-semantically* related condition. These results indicate that the partial overlap between phonological or semantic codes of words supports novel word recognition more than if they overlap entirely.

Keywords: toddlers, phonological features, semantic features, eye-tracking, preferential-looking task, novel target recognition

Effects of Words' Phonological and Semantic Overlap in Novel Word Recognition.

Decades of research showed young children's sensitivity to the overlap among the phonological makeup of labels and the concepts associated with words[11]. For instance, it has been reported that young children are sensitive to different sources of similarities between words, such as phonological (Avila-Varela, Arias-Trejo et al., 2021; Mani & Plunkett, 2010, 2011), semantic (Arias-Trejo & Plunkett, 2009, 2013; Styles & Plunkett, 2009, but see Avila-Varela, et al. 2021), and phono-semantic (Altvater-Mackensen & Mani, 2013a; Angulo-Chavira & Arias-Trejo, 2018; Mani et al., 2012; for a review, see Mani & Borovsky, 2017).

Nevertheless, more research about the impact of the phonological and semantic overlap between novel label-referents associations deserves further investigation, given that the recognition of recently acquired words might be affected differently than the recognition of familiar words (see Storkel el al., 2006). Also, testing different learning scenarios where novel label-referents overlap phonologically, semantically, on both, or are unrelated; will provide additional evidence on which is the more beneficial context for word learning in young children. Therefore, the current study examines toddlers novel word recognition after the following learning conditions: a *phonologically* related, where two novel labels shared the initial syllable (e.g. /simi/ and /sinqa/); a *semantically* related, where referents belonged to the same category (e.g. "food"); a *phono-semantically* related, where labels shared the initial syllable and referents belonged to the same category; and D) *unrelated*, where labels were phonologically dissimilar (e.g. /simi/ and /alku/), and their referents belonged to different categories (e.g. "food" and "musical instrument"). Here, fixations towards the novel target were considered the measure of novel target recognition, and total-looking-time and time-course analyses were carried out on those data.

In what follows, the LEX model (Regier, 2005). of word learning will be reviewed. Next, previous work on the effect of words' phonological features in word learning, research on the role of novel referents' semantic features on word learning, and research where both—phonological and semantic features were combined—will be summarized.

The LEX model (Regier, 2005) is a model for word learning based on computational simulations in which the phonological (i.e., word form) and semantic (i.e., meaning) aspects of words are considered. This model proposes that the crucial mechanism in play for young children's growing ability to learn new words relies on selective attention to relevant aspects of word forms (e.g., phonemes) and meaning, which reduces memory interference. According to this model, for a given word form, the model produces a probability distribution over associated referents (i.e., exemplars of meaning); and vice versa, given a referent, the model produces a probability distribution over associated exemplars of form. These associations are mediated by a single set of associative links, connecting the two hidden layers of the model. Form exemplar nodes and meaning exemplar nodes are associated one to one through associative weights. Additionally, there are also weights encoding selective attention to each dimension of form (e.g., for phonetic

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[11] The reader should notice that in this manuscript, the term "word" will be used to refer to a well-known familiar word (e.g., "dog"); while the term "label" will be used to refer to a word recently heard and to refer to non-real words (e.g., "meb"). Similarly, the term "object" will be utilized to mention a thing to which well-known words refers (e.g. the picture of a dog or a toy with a dog shape); and the term "referent" will be used to speak about the novel object introduced associated with the novel label (e.g., the picture of a no familiar or random object to be associated with the label "meb").

features such as voicing or pitch that helps to discriminate among minimally different words as "pat" and "bat") and each significant dimension of meaning (e.g., shape or color that helps to differentiate referents belonging to the same category). The weights encoding selective attention stretch and compress words forms with meanings on clusters. When a novel word or referent is presented, no other exemplars will be near (in the form or meaning space) because the novel word by definition differs from other words along significant dimensions, thus reducing interference with other similar forms or meanings.

The LEX model has some predictions concerning similarities in word form and meaning, i.e., "Because weight updates are affected by both form and meaning, two words that are similar in form and have similar referents should be maximally difficult to learn and keep distinct in memory, two words that are similar in only one or the other should be of intermediate difficulty, and two words that are dissimilar in both form and referent should be relatively easily learned" (Regier, 2005, p. 848). Therefore, the current study results will be interpreted according to the LEX model.

Role of Words' Phonological Features in Word Learning

Previous research has shown that similar sounding words impact word learning (Altvater-Mackensen & Mani, 2013; Breen, et al. 2019, Fennell & Waxman, 2010; Yoshida et al., 2009). For instance, In Altvater-Mackensen´s study (2013), participants were initially pre-exposed to some words (e.g., “Löffel”, Eng. “spoon”); and later, the detection of phonologically related novel words (e.g., “Löckel”) and unrelated novel words (e.g., “Sotte”) was measured while they heard fluent speech. Here, participants recognized better those novel words that sounded similar to the familiar pre-exposed words. This finding suggests that the phonemes sequence of the words presented during pre-exposure was activated in the following phase of fluent speech processing, which resulted in easier detection and segmentation of words that sounded similar to the familiarized words. Thus, indicating that the pre-exposure of a similar phonological pattern to a novel word to be learned supports their acquisition.

In addition, a study where phonotactic regularities of novel labels were manipulated found that children with high productive vocabulary benefited from such phonological overlap to learn novel labels (Breen, et al. 2019). Specifically, in Breen et al. (2019) study, 2-year-old participants were familiarized with a list of novel labels that followed a phonotactic regularity (e.g., a shared onset /b/, /bilu/-/bote/-/bugo/). They found that while children with lower vocabulary learnt labels congruent and incongruent with the familiarized list (e.g., /bafto/ and /koovai/, respectively), their pairs with higher vocabulary learnt better the novel congruent words than the incongruent ones.

The beneficial role of words’ phonological features on word learning also has been shown in studies of words’ age of acquisition. For instance, a tendency to acquire new words that sound similar to familiar words (namely, words with dense phonological neighbours) has been reported (Storkel, 2004, 2009). In addition, a recent study by Fourtassi, Bian & Frank (2020) modelled networks based on the phonological overlap between familiar words of children under three years of age. Each node represented a word in these phonological networks. The edges connecting two nodes represented whether a minimum of two operations (e.g., insertions, deletions, substitutions) were required to change their International Phonetic Alphabet transcript strings from one word-node to another. Their results indicate that phonological connectivity was associated with words’ age of acquisition in nine out of the ten languages examined, thus suggesting that high phonological connectedness of words supports learning.

Additional research with 14-month-old children learn similar-sounding words (e.g., /bin/ and /din/) when the referent is highlighted during a learning phase (e.g., with clear sentential contexts and word-referent training) (Fennell & Waxman, 2010); and when a preferential-looking paradigm was implemented (Yoshida et al., 2009). Specifically, in Fennell & Waxman´s (2010) study the authors, in Exp. 1., presented the novel label on carrier phrases (e.g., "Look at the din!", "There is the din!"); and, in Exp. 2., they made clear the status of the referent of the novel object by the presentation of images of familiar objects (e.g., a cat) accompanied by their names in isolation ("Cat!").

Moreover, research with older children between 18 to 23 months of age, shows that they can learnt similar sounding novel words (Werker et al., 2002; Bailey & Plunket, 2002; Swingley and Aslin, 2000).

On the other hand, research also highlights a possible impairing effect of phonological overlap among novel labels on word learning. For example, Nazzi (2005) found that while 20-month-old toddlers learned novel labels which were phonemically different from each other (e.g. /pize/ and /mora/), they learn in a lower degree novel labels that minimally differed at the consonantal level (e.g., /pize/ and /tize/; see also Nazzi & New, 2007) but not when the labels minimally differed at the vowel level (e.g., /pize/ and /paze/).

The contrariness of these findings can be explained if we consider Storkel et al.'s (2006) proposal, which suggests that phonological similarities impact differently to each aspect involved in word learning. On the one hand, the phonological overlap might drive attention towards this overlap, thus, supporting learning. This suggestion is reinforced with the findings of ease of segmentation found in 7-month-old infants who segmented from speech better novel words that sounded similar to pre-exposed words than words that sounded different to pre-exposed words (Altvater-Mackensen & Mani, 2013b). On the other hand, the phonological similarities can hinder the integration of the novel mental representation on the long term memory —given the high degree of phonological overlap with other similar-sounding words' mental representations already stored. This aligns with Nazzi´s (2005) results, which show that it was not easy to learn similar-sounding words for young children.

Moreover, the contrariness of the findings on Altvater-Mackensen and Mani´s study (2013b) and Nazzi´s (2005) study can be explained on the different processes tested on each study. That is while, Altvater-Mackensen examined segmentation, Nazzi studied referent learning. Therefore, the results of Altvater-Mackensen speak on the role of phonological information on novel word segmentation (extracting single words from fluent speech stream) and the results of Nazzi on referent learning (mapping between novel objects with novel labels). In addition, the difference in age of the participants tested, 7-month-old infants (Altvater-Mackensen & Mani, 2013b) and 14-month-old toddlers (Fennell & Waxman, 2010), and older ones (Fourtassi et al., 2020; Nazzi, 2005; Storkel, 2004, 2009) could also explain the difference in results. Thus, the older the participant, the higher is the number of words that can sound similar to the novel word to learn, so similar sounding words in her mental lexicon might interfere with integrating the recently acquired word in her mental lexicon.

These findings highlight that young children can learn words that sound similar to each other (Fennel & Waxman, 2010; Yoshida, 2009; Breen et al., 2019) and to other familiar words (Altvater-Mackensen & Mani, 2013b, Storkel, 2004, 2009; Fourtassi et al., 2020). However, there is also evidence indicating that children might find it challenging to learn words that sound similar to each other (Nazzi, 2005). Nevertheless, what remains unclear are the specific conditions under which phonological similarities between novel labels are beneficial or not hinder word learning.

Thus, more information about the potential beneficial or detrimental effect of phonological overlap in novel labels on word acquisition is needed, as presenting words that sound similar to each other could support their learning, as their share phonological features.

Therefore, in the current study, we compared novel target recognition in a *phonologically* related, with on the one hand *a phono-semantic* related condition; and on the other with an *unrelated* condition to disentangle the role of phonological overlap on word learning in the presence and absence of a semantic link between novel referents (namely, phono-semantic and unrelated learning conditions).

Role of Words' Semantic Features in Word Learning

Previous work exploring the effect of referents' semantic features on word learning found that the mental lexicon's organization may influence accuracy in familiar word recognition and, according to the leverage learning perspective, it could boost word learning. The leveraged learning perspective posits that knowledge of some words supports the learning of others, which is the case for the learning of words that belong to semantic populated domains (Borovsky et al., 2016b). For instance, Borovsky and collaborators (2016b) found that 24-month-old toddlers learnt better novel words which were new exemplars of dense categories (here, categories to which children know plenty exemplars, e.g., animal) than less known categories (e.g. clothing items). The findings showed that while participants recognized the novel exemplars on both high- (e.g., "hedgehog" a novel animal) and low-density categories (e.g., "banyan" a novel clothing item), novel word recognition was more robust and accurate for the high-density novel words than in the low-density novel words. These results indicate that 2-year-old children's previous knowledge of category exemplars supports word learning (see also Peters, Kueser & Borovsky, 2021). Thus, these results speak on the leveraging effect children's previous knowledge of semantically related words has on familiar and novel word recognition.

More evidence supporting the leveraging role of semantic overlap on word learning can be found in studies applying network science methodologies (Hills, Maouene, Riordan & Smith, 2010; Hills et al., 2009a, 2009b; Peters & Borovsky, 2019). In those studies, children's vocabularies have been modelled as networks —where nodes represent words and links are the relationships between them (e.g., whether words belong to the same taxonomic categories, or the items share perceptual features). Some of those studies found an underlying semantic structure based on shared perceptual features across words on the early lexicon (Hills et al., 2009a, 2009b; Peters & Borovsky, 2019). These findings suggest that children do not learn words randomly but rather following an underlying mechanism grouping items according to shared semantic features. For example, the familiarity of a child with words referring to fruits (e.g., "banana", "apple", "orange") can facilitate the learning of a novel label referring to a fruit she is encountering for the first time. Thus, the learning of the novel label "mango" might be facilitated by her previous knowledge associated with other fruits (e.g., "sweet", "small", "eaten as a snack or dessert").

Extending the leverage perspective, one could consider that even the similarities between novel referents might support learning. In this line a study from Wojcik and Saffran (2013) suggests that children can encode similarities between novel referents. In their study, children were taught four novel label-referent associations divided into two pairs of referents that shared perceptual features, namely shape and colour (e.g., round-blue vs star-red). In a habituation task, 2-year-old children heard longer to a list of novel labels of referents with shared features than to a list of novel labels of referents from different categories (here, dissimilar referents, Exp. 1). In addition, toddlers learnt all labels tested in the study, as shown in a preferential-looking task, where they looked significantly more at the targets upon hearing the novel labels than in a pre-naming phase (Exp.2). Therefore, suggesting that children learnt the novel label-referent associations and encoded referents' perceptual similarities. These findings indicate that the overlapped semantic features shared between the referents supported the learning of their labels.

In sum, this review suggests that children encode semantic relations between referents to support their word learning. However, in the behavioural study of Borovsky and collaborators (2016b) mentioned here, the phonological overlap of the novel labels was excluded. That is, the novel labels to learn always sounded dissimilar to each other (e.g., "hedgehog", "banyan"). Therefore, what remains unknown is if conditions where shared semantic similarities between novel referents support word learning even when novel labels sound similar; when novel referents share no semantic overlap, but their labels sound similar to each other; and when there is no overlap.

Therefore, in the current study, we compared novel target recognition in a *semantically* related, with on the one hand a *phono-semantic* related condition, and on the other with a *phonologically* related condition, and finally with an *unrelated* condition to study the role of semantic overlap on word learning in the presence and absence of a phonological link between novel labels.

Role of Words' Phono-Semantic Features in Word Learning

Previous studies have studied these sources of information combined. For example, in the study of Twomey and collaborators (2014), they found that children's word learning benefits from the presence of multiple novel candidates in the same category. Specifically, in their study, 24-month-old children were presented with novel exemplars that belong to a novel category (e.g., /doff/), which were highly different across multiple dimensions (e.g. colour and shape) or not (the exemplars differed between them only in colour). Then, in a retention test phase (after a short delay), only those exposed to the exemplars that differed only in one dimension remember the novel labels. Thus indicating that category learning is possible in young ages if within-category variability is not excessive. Twomey et al. (2014) present a study where phonological and semantic aspects are combined, as the same label (e.g., /doff/) was used to designate different members from the same category (e.g., objects belonged to the category "doff" or "cheem"). Thus here, the phonological and semantic domains are highly overlapped.

In another study, Namy and Gentner (2002) presented 4-year-old children to multiple, variable exemplars labelled with a common novel name (e.g., naming with the label "blicket" both an apple and a pear), and then asking participants to identify a "banana" (same category "fruit") or a "balloon" (perceptually similar object to the apple and pear) as a "blicket". The results show that the presentation of that common label (e.g., "blicket") facilitated grouping the multiple items among the same taxonomical category (e.g., "fruit"). That is, children tend to extend the use of the same label to different objects based on the belonging to the same taxonomical category (e.g., tend to classify a banana as a "blicket" upon seeing that both an apple and a pear are "blickets"). This result suggests that phonological and semantic overlap does not impede children from learning novel words to refer to familiar objects in categorization tasks.

The reviewed results suggest that children’s word learning is also possible when novel words overlap in the phonological and semantic domains. Nevertheless, what deserves more research is whether these combinations of phonological and semantic features always boost word learning or if there is a critical point after which the amount of overlap between novel associations prevents learning. In addition, would be important to compare it, with situation were only one source of information is overlapped. Thus, in the current study, we will compare novel word recognition in situations where words overlap at both phonological and the semantic domain, with an unrelated condition (where there is no phonological or semantic overlap) and with one domain overlap conditions (the semantic and the phonologically related conditions).

The Current Study

At this point, we can conclude that young children can learn novel label-referents associations where the labels sound similar to familiar words (Altvater-Mackensen & Mani, 2013). Phonological and semantic lexical links also have been simultaneously examined in word recognition studies applying the visual-world-paradigm with adults (e.g., Allopenna et al., 1998; Huettig & McQueen, 2007; Yee & Sedivy, 2006) and children (Chow et al., 2017). Typically, these studies found that images of phonologically related words are fixated first, followed by images of semantically related words upon hearing the target. These results indicate that during word processing, initially phonologically related words to the target are accessed first and subsequently to semantically related words are accessed during speech processing (Huetting & McQueen, 2007; Allopenna et al., 1998; Yee & Sedivy, 2006; Chow et al., 2017).

In addition, phono-semantic links’ impact on word recognition also has been studied implementing the visual-world-paradigm with young children (Huang & Snedeker, 2010; Mani et al., 2012). For instance, Mani, and collaborators (2012) presented 2-year-old children with a prime stimulus that was phonologically related at the onset (Exp. 1) or at the rhyme (Exp. 2) with a mediating word, which was semantically related to the displayed target image. Thus, the only way that a word like “clock” to facilitate the recognition of the word “shoe” is through the activation of a phono-semantically related word such as “sock”. Two-year-old children, as older children and adults, also showed phono-semantic priming effects. Thus, providing additional evidence to the activation of phonologically related words as speech is being heard —at the onset and rhyme— at the lexical level of representation, which elicited the activation of semantically related words to them.

Given that it is well established that children activate words based on their phonological and semantic relationships separately, test compound links (i.e., phono-semantic) will provide additional information about how much single versus compound overlap between words contributes to novel word recognition.

Some models of speech recognition, such as the *Distributed Cohort Model* (Gaskell & Marslen-Wilson, 1997) or the *Cascaded Models* of word recognition (Huettig & Altmann, 2011; Johnson et al., 2011; Johnson & Huettig, 2011; Mani et al., 2013) consider the role of phonological and semantic cues on words recogntion. For instance, The *Distributed Cohort Model* proposes that phonological features from the speech signal and semantic aspects related to the context in which the novel word appears are integrated for recognition simultaneously. Therefore, if both domains phonological and semantic overlap on novel words, word recognition will experience a higher competition until the speech signal is complete and it is possible to identify the intended referent. In addition, *Cascaded Models* of word recognition postulates that during lexical access, there is cascaded activation of phonological, semantic and perceptual associates to the words heard.

However, what is the role of the phonological and semantic features of labels on word learning? Test compound links will be interesting to test the predictions of the LEX model of word learning (Regier, 2005), which suggest that selective attention is at play when learning novel label-referents associations. According to this model selective attention will discriminate among similar sounding words and semantically related concepts based on significant aspects. Which in turn will reduce memory interference from other related concepts stored in memory. The LEX model predicts better learning in unrelated conditions followed by phonological only or semantically only related novel associations and highest difficulty in phono-semantic related novel associations.

In addition, the leveraging approach of word learning proposes that the previous language support the acquisition of semantic and phonological related words (e.g., Borovsky et al., 2016b; Storkel, 2004, 2009), although the relative contribution of these domains has been examined separately. Therefore, the results of the comparison of learning conditions where phonological and semantic domains are both combined or not will provide additional evidence to the theories of speech recognition regarding the relative contribution of phonological and semantic domains in speech processing.

Thus, in the current study, we compared novel target recognition across four learning conditions, manipulating the phonological and the semantic domains (see Table 7). The phonological domain was manipulated through the presentation of novel labels that share or not the initial syllable. This manipulation was implemented, as previous studies with infants have shown sensitivity to shared initial syllables (e.g., Avila-Varela, Arias-Trejo et al., 2021; Ramos-Sanchez & Arias-Trejo, 2018). The semantic domain was manipulated based on clarifying the objects referents belonging or not the same category. The categories tested were “food” and “musical instrument”. Therfore, the new labels had the same initial consonant-vowel syllable in the phonologically and phono-semantically related conditions, here /**si**/ (/**si**mi/ and /**si**nqa/). While in the *semantic* related and *unrelated* conditions, the labels were phonologically dissimilar (/simi/ and /alku/). In the *semantic* and the *phono-semantically* related conditions, both referents belonged to the category “food”. Contrary, in the *phonologically* related and *unrelated* condition, one referent belonged to the category “food”, and the other belonged to the category “musical instrument” (for a summary, see Table 7).

Table 7

Novel label-referents associations taught in each learning condition.

	Novel label-referents association		*Does the novel label-referent association has a*	
Learning Condition	Blue object	Red object	*phonological overlap?*	*semantic overlap?*
Phonologically Related	/**si**mi/ + (food)	/**si**nqa/ + (musical instrument)	yes	no
Semantic Related	/simi/ + (food)	/alku/ + (food)	no	yes
Phono-semantically Related	/**si**mi/ + (food)	/**si**nqa/ + (food)	yes	yes
Unrelated	/simi/ + (food)	/alku/ + (musical instrument)	no	no

Note: in parentheses is the intended category taught in each learning condition. Here, the referents are the objects shown to the participants.

The overlapped features in each learning condition are highlighted in bold.

V. Method

Participants

Data from 104 (50 females, 54 males) monolingual German toddlers were included in the analysis. Additional 14 participants were tested but excluded for analysis due to failing to provide at least one valid trial by test block —see section “Exclusion criteria”—(*N* = 7); fussiness (*N* = 4); experimenter error (*N* = 1); technical failure (*N* = 1); and for being bilingual (*N* = 1). See Table 8 for details about the number of participants excluded per learning condition. They were on average 21.77 months of age (range = 20.60 - 23.30) at the time of the study. Overall, they had an exposure of fewer than 2 hours a day to an additional language at home and had no known hearing or visual problems. Most of the participants’ caregivers completed high school and university studies, they also had a full or part-time position at the time of the study. All participants were recruited from the laboratory database. For details of participants’ demographic information, and exclusion criteria in each learning condition, see Table 8.

Table 8

Participants’ demographic information and details of exclusion criteria.

Learning Condition	N (females)	Average age	Age range	Excluded participants
Phonologically Related	29 (15)	21.79	20.60-23.10	1 (a)
Semantic Related	25 (11)	21.73	20.73-23.30	2 (a)
Phono-Semantically Related	26 (12)	21.73	20.70-23.27	2 (a), 4 (b), 1 (c)
Unrelated	24 (12)	21.85	20.70-22.93	2 (a), 1 (d), 1(e)

Note: N stands for the number of participants included in final analyses by learning condition, the number in parentheses is the number of females. Participant exclusion criteria are indicated in parentheses as a) for failing to provide at least one valid trial by test block (see section “Exclusion criteria”); b) fussiness; c) experimenter error; d) technical failure; and e) bilingual child.

Auditory Stimuli

The speech stimuli were words from Quechua *simi* /simi/, *sinqa* /sinqa/ and *alqu* /alku/[12] (Engl. “mouth”, “ear” and “dog”, respectively). Real words were presented given that they had gone through cultural evolution, which has been associated with better learning (e.g., Silvey, Kirby & Smith, 2015; Tamariz & Kirby, 2016). These words were in accordance with German phonology. For example, /simi/ sounded similar to the German labels **si**tzen and **Mi**ete (Engl. “to sit” and “rent”, respectively). The label /sinqa/ sounded similar to the German word **Sinke**r (Engl. “a person who makes something sink”). Finally, the label /alku/ sounded similar to the German **all**gemein and Ak**ku** (Engl. “generally”, and “battery” respectively). In addition, no family reported to had heard or used those labels before.

Auditory stimuli were recorded by a native German female speaker using infant-directed speech. For recordings of the videos and audios presented in the study, she was instructed to produce the speech stimuli in infant-directed speech and follow the stress pattern of German (which usually falls on the first syllable). The novel target labels (simi, sinqa and alku) were recorded in isolation and complete sentences. However, to maintain the precise timings of target labels onsets, carrier phrases were created, and target labels were inserted into them. Thus, words were presented in isolation or continuous speech when necessitated by the type of trial presented (i.e., *familiarization*, *training* or *testing* trials). Auditory stimuli processing was carried out with GoldWave software (St. John’s, Newfoundland and Labrador, Canada). First, the sentences and isolated tokens were spliced from the entire recording. Next, background noises, head and tail clicks were removed manually. Finally, the targets and prime sentences were spliced together to form a single audio file.

Procedure

The Georg-August-Goettingen University ethics committee approved the study before the start of data collection. Before the visit, caregivers filled out a subset of the German communicative inventory (Fragebogen zur fruhkindlichen Entwicklung; Szagun, Stumper, & Schramm, 2009) to account for participant vocabulary sizes.

At the beginning of the testing session, families were welcomed to a room and given a few minutes to familiarise themselves with the environment and experimenter. Then, caregivers were informed about the goal and procedure of the study. Next, one caregiver signed the informed consent form and filled out a socio-economic questionnaire.

The study comprised a pre-exposure phase followed by an on-screen phase. In total, the experimental session lasted approximately forty-five minutes, and when the study was completed, children were rewarded with a book and a certificate. In the pre-exposure phase, children were presented with the real version of the objects for 3.5 minutes each (see Figure 13). In this phase, objects presentation order was counterbalanced across participants. Then, the participant and caregiver were taken to the eye-tracker room, where children sat either in a

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[12] The reader should notice that the international phonetic alphabet transcriptions for the Quechua word “simi” is /simɪ/, for “sinqa” is /sɛŋɣɑ/, and for “alqu” is /ałqɔ/. For the sake of clarity and respecting how words were pronounced in the study, we referred to them as /simi/, /sinqa/ and /alku/, respectively.

car seat or on their caregivers' lap. Caregivers were asked to shut their eyes and not repeat what they heard during the experiment.

Figure 13

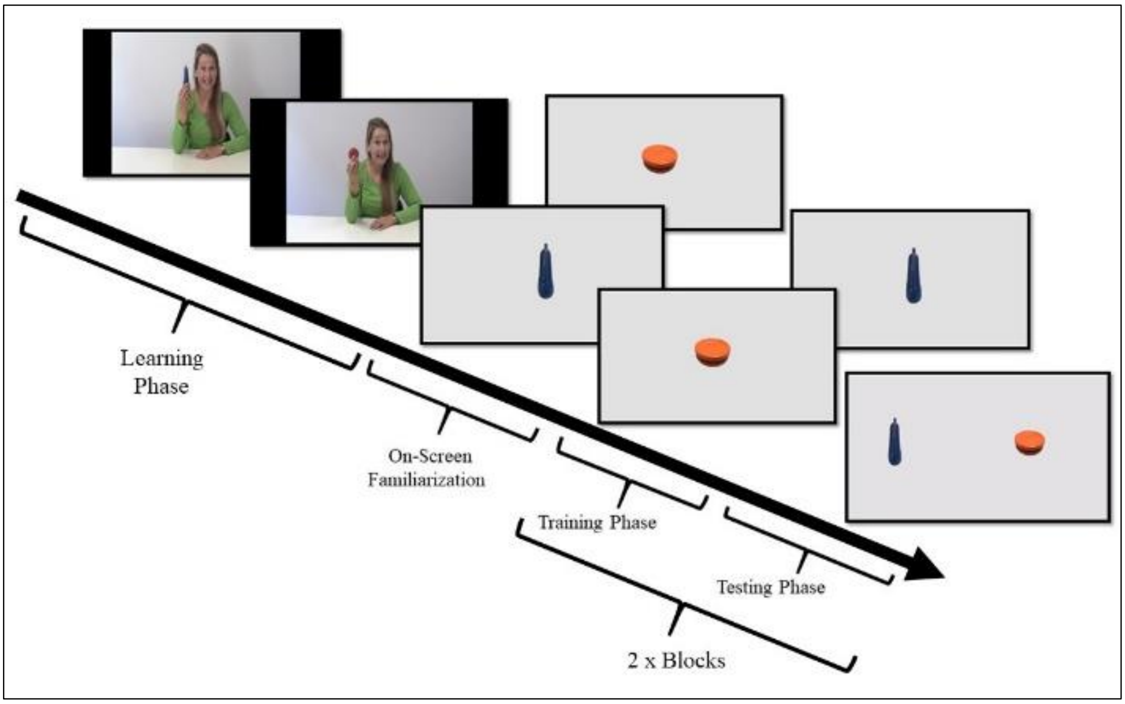
Objects presented to participants.

Note. The blue object (right) was always associated with the label /simi/; and depending on the learning condition, the red object (left) was associated with the label /sinqa/ or /alku/.

Next, the on-screen phase started with a learning phase, for which we adapted the procedure utilised in Mani and Plunkett (2008). In this phase, initially, we presented a familiarisation phase, followed by two blocks of training and test (see Figure 14). Examples of the videos presented on the on-screen phase of the study are available on the Open Science Framework at https://osf.io/ybxuk// (Avila-Varela, Hartmann & Mani, 2022).

Figure 14

Study on-screen event sequence**.**



Learning Phase

In the learning phase, a video of a female German speaker appeared for a mean of 48.8 seconds (range length of 46 to 52 seconds) per referent, one after the other. In each learning video, she repeated the referent's label six times. On two occasions, she used introductory and general expressions, such as, “Oh! Guck mal! Was habe ich hier! Das ist ein [label]!”; “Ja, das ist ein [label]!” (Engl. “Oh, look what I have here! This is a [label]!”; “Yes, this is a [label]!”; respectively). To close the learning phase, she used the expression “Sag tschüss zum [label]!” (Engl. “Say goodbye to [label]!”).

On the remaining three occasions, she used utterances and congruent mimic to indicate that the referent belonged to the category “food” or “musical instrument”. For the “food” category, she used the sentences: “Wir können das [label] zerschneiden!”, “Wir können die zwei Stücke vom [label] probieren!”, and “Das [label] ist super lecker!” (Engl. “We can cut the [label]!”, “We can taste two pieces of the [label]!” and “The [label] is delicious!”, respectively). In the case of the musical instrument, she used the expressions: “Wow shau mal, mit das [label] können wir Music machen!”; “Wir können das [label] schütteln! Oh das kling gut!”; and “Wir können mit dem [label] auf dem Tisch klopfen!” (Engl. “Wow, look! We can make music with the [label]!”; “We can shake the [label]!”; Oh, that sounds good!”; and “We can knock on the table with the [label]!”; respectively).

On-Screen Familiarization

After the learning phase —where the actress named the objects using the novel labels and performed actions indicating the categories to which they belonged—a on-screen familiarization phase was presented. We included the familiarization phase to make familiar the children with the isolated images of the referents, i.e., here, the images are presented without background.

In doing so, we pretend to familiarize children with how the images of the referents will look like in the testing phase.

During the familiarization phase, a five-second video per referent was presented. In each video, the referent was moving up and down in the centre of the screen accompanied by sentences, such as “Oh shau mal! Du kennst das!” or “Wow Guck mal! Was ist das?” (Engl. “Oh look! You know this!”; or “Wow look! What is that?”; respectively). The order of appearance of the referents videos was counterbalanced across infants.

Training Phase

Following the on-screen familiarization phase—where children were presented with the referents images without the background, see Figure 14—we introduced a training phase. In the training phase, we presented videos with the images of the referents accompanied by their labels placed into sentences. The goal of this phase was to repeat the correct mapping novel label-novel referent in the same format in which later novel target recognition will be measured in the test trials.

Thus, participants were exposed to four training trials presented in two consecutive blocks. Each block comprised two videos, one per referent. The referent moved up and down as in the familiarization phase. Here, the referents were labelled twice per trial in the carrier phrases “Oh, Das ist ein [label], ein [label]!” (Engl. “Oh, this is a [label], a [label]!”). The onset of the first token of the novel label was set at 2500ms on trial, and the second token was set at 4000ms on trial. The object-label associations from the familiarization and learning phases were maintained. The difference between this phase -training- and the on-screen learning phase is that later, the actress is naming in the novel referents with the novel labels in a simulated naturalistic play representation. In contrast, in the training phase, novel labels and novel referents lack this naturalistic context, and the associations label-referents are presented in isolations. The goal of these trials was to repeat participants the associations words-objects tested.

The order of presentation of trials was counterbalanced across blocks and infants. The first block of training was presented after the on-screen familiarization, then it was followed by the first block of testing. The second block of training and testing followed the first block.

Two attention-getter videos were included, one was presented between the first block of training and the first block of testing; and the second, before the presentation of the second block of training and testing. The images presented in the attention getter videos were colour pictures of a flower and an elephant from public libraries available on the Internet. In the attention-getter videos; pictures were centred on the screen and then moved up and down. The attention-getters were manually terminated when the participants looked at them.

Testing phase

Toddlers were presented with four testing trials split into two test blocks. Each block comprised two videos, one per referent label according to the learning condition (/simi/ and /sinqa/; or /simi/ and /alku/). In each test trial, side-by-side images of the two novel referents were displayed for five seconds. The pictures remained in the same location during the trial, and the novel labels were included twice in the phrase “Hey, wo ist das [label], das [label]?” (Engl. “Hey, where is the [label], the [label]?”). The first token of the novel label was set at 2500ms on trial and the second at 4000ms on trial. Each picture appeared equally often on the left and on the right side. Object position was counterbalanced across participants, trials and test blocks.

Statistical Analyses

The Dependent Variable

A custom code written in R Version 4.0.5 (R Core Team, 2013) was used to process fixation data exported from the eye tracker. The eye tracker provides an estimate of X and Y coordinates of children's fixations on the screen, with one data point every 16ms. Data were included only when the eye tracker reliably acquired them from one or both eyes. These time stamps were then divided into 40ms time bins. Areas of interest were defined on X and Y coordinates according to the size of target and distracter images (300 by 300 pixels) plus a framework of 60 pixels (a total area of 360 by 360 pixels), positioned 360 pixels from the height of the monitor and with a separation of 480 pixels between them.

For analysis, we included only data from the trials presented in the testing trials. Each participant saw eight test trials, divided into two testing blocks (four per block, two per referent). Test trials were divided into an initial baseline phase and a recognition phase, the latter one started with the first token of the target label (2500ms). From the baseline phase, to exclude fixations in response to the pictures appearing on the screen, only fixations from 240ms to 2000ms after trial onset were included (for a similar approach, see Eiteljoerge, Adam, Elsner & Mani, 2019b). From the recognition phase, given that children may need more time to recognize newly learned labels, fixations from 400ms to 2200ms after the target first token were included (for a similar approach, see Ackermann et al., 2020; Breen, Pomper & Saffran, 2019).

The dependent variable was the corrected proportion of target looking (PTL_corr), which was calculated as the difference between the average PTL (PTL = target looking + distracter looking/target looking) during the baseline phase and the PTL in the recognition phase. We implemented this measure to correct for possible participants' visual preferences towards one of the objects in particular trials (see Bergelson & Aslin, 2017; Eiteljoerge, et al., 2019b).

Exclusion Criteria

With the goal of removing from analyses trials in which participants were not focused on the task, we excluded trials in which infants fixated at the objects fewer than two standard deviations from the overall mean looking-time per trial (here, lower 2sd = 645ms) (for a similar approach, see Eiteljoerge, et al., 2019a). After applying that criterion, data of seven participants were discarded for their failure to provide at least one valid trial in each test block (that is, all included participants provided a minimum of two valid trials across the experiment, see Table 8). In summary, in the *phonologically* related condition, we included 90.91% of the trials (*n* = 210). In the *semantic* related condition, we included 97.00% of the trials (*n* = 194). In the *phono-semantically* related condition, we included 92.79% of the trials (*n* = 193). Lastly, in the *unrelated* condition, we included 92.59% of the trials (*n* = 175). Analyses were performed on the remaining data set.

Statistical Analyses

All statistical analyses were carried out in RStudio (version 1.1.463; and R version, 4.0.5, R Core Team, 2013) using the lme4 package version 1.1-26 (Bates, Mächler, Bolker & Walker, 2015), the multicomp package version 1.4-16 (Hothorn, Bretz &Westfall, 2008) and the stats package version 4.0.5 (R Core Team, 2013).

First, we executed generalized linear mixed-effects models (GLM) with the total target looking (aggregated PTL_corr) on each learning condition (phonologically rel., semantically rel., phono-semantically rel., and unrelated) and test blocks (first vs second). Then, we analysed the time-course on fixation data using mixed-effects growth curve analyses (GCA; Mirman, 2017) at each time bin throughout the time window for analyses per test block.

V. Results

Data are plotted in Figure 15, and Table 9 summarizes the mean and standard deviations of aggregated corrected target looking in each condition and test block. The data and analysis scripts are stored on the Open Science Framework at https://osf.io/ybxuk// (Avila-Varela, Hartmann & Mani, 2022).

Table 9.

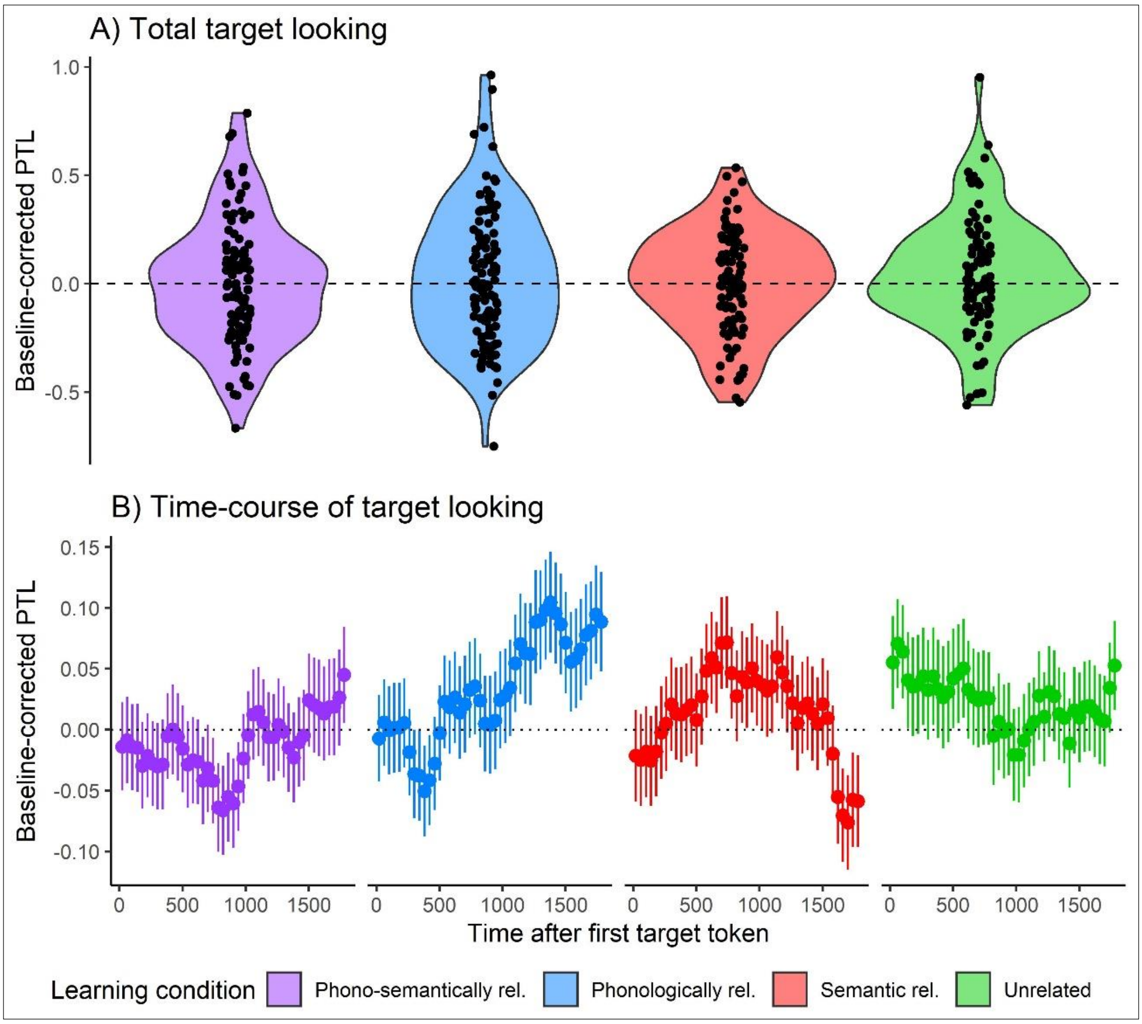
Statistic descriptive of the baseline-corrected target looking.

	Test Block			
	First		Second	
Learning Condition	*Mean*	*SD*	*Mean*	*SD*
Phonologically Related	0.038	0.243	0.021	0.247
Semantically Related	-0.038	0.147	0.054	0.144
Phono-semantically Related	-0.026	0.146	-0.003	0.178
Unrelated	0.055	0.149	0.008	0.193

Note: Scores of 0 reflect target looking at chance levels, positive values indicate target looking, and negative values distracter looking. Given that the values of the correct proportion of target looking are small, for the sake of clarity, those are reported using three decimals.

Figure 15

Proportions of the baseline-corrected proportion of target looking (PTL_corr)



Note. Panel (A) shows averaged across trials on each learning condition, where dots represent the participant's mean scores of PTL_corr. Panel (B) displays time-course of PTL_corr by learning condition. Here, points represent the mean and lines represent the standard error.

Generalised Mixed Effect Model

A generalised mixed effect model (GLM) was fitted to the aggregated PTL_corr to assess whether target fixations varied across learning conditions and by test blocks. Interactions between learning condition and test block were included in the GLM model, as fixed effects. As random effects, the slope of PTL_corr per test block and per target label for each participant were included. The levels of the categorical factors were assigned to contrast codes as follows: test block (first = 1, second = -1); target label (simi = 1, alku/sinqa = -1); then were sum-coded so that the interactions in the model refer to the contrast across test block and target labels. The levels of the learning conditions were coded as *comparison 1*: phono-semantically rel. = 0, phonologically rel. = 1; *comparison 2*: phono-semantically rel. = 0, semantic rel. = 1; and *comparison 3*: phono-semantically rel. = 0, unrelated = 1. The resulting models' lmer syntax was: PTL_corr ~ Condition * blockSum + (1 + blockSum | part) + (1+targetSum | part)

Statistical significance (*p*-values) for individual parameter estimates was assessed using the normal approximation (i.e., treating the *t*-value as a *z*-value). In all models, collinearity between variables was checked using the measures kappa (κ) and the variance inflation factor (VIF) from the regression-utils.r and mer-utils.r functions (Frank & O'Hora, 2014, retrieved from GitHub). Thresholds on κ > 15 and VIF > 10 are considered as indicators of the independent variables being highly correlated to each other (e.g., see Tomaschek, Hendrix & Baayen, 2018).

The output of the GLM model is presented in Appendix S. The GLM model (κ = 5.81 and VIF = 3.94) parameter estimates showed no significant main effects or significant interactions (*p*s > .294). Figure 15B shows the time course of PTL_corr by learning condition as time unfolds in the trial.

Additional pairwise comparisons manually coded the levels in the *learning condition* to confront related conditions against the unrelated condition, resulting in Comparison 1: *unrelated* = 1, *phonologically rel.* = -1; Comp. 2: *unrelated* =1, *semantic rel.* = -1; and Comp. 3: *unrelated* = 1, *phono-semantically rel*.= -1. We used the glht function from the multcomp package to compute the pairwise comparisons. Results revealed no significant differences in PTL_corr across conditions (*p*s. > .184) (see Appendix T).

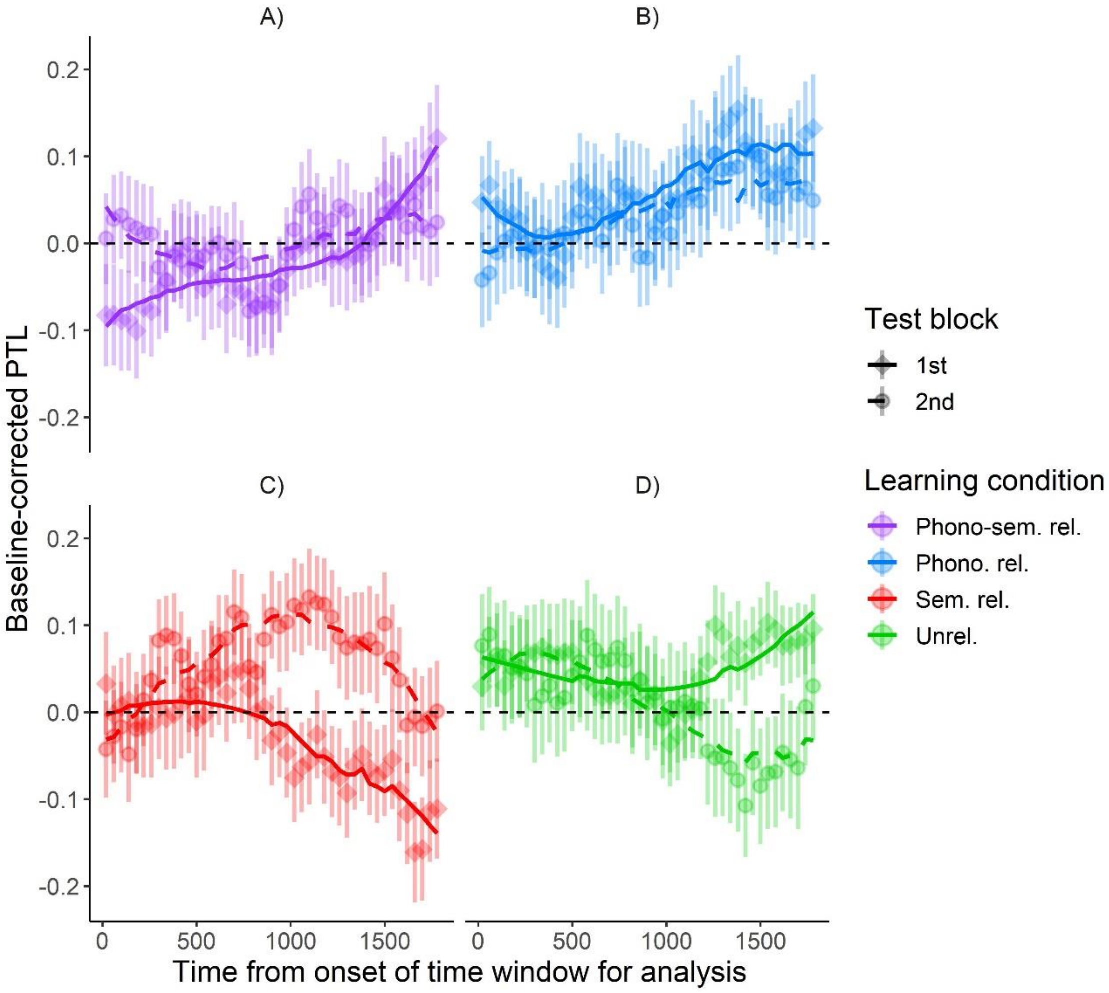
Overall, the results from the total looking time analyses (GLM) indicate that there was no accurate novel target recognition in any of the learning conditions or test blocks. However, given that learning conditions may had impacted the curves of target looking as the trial progressed, and as suggested in Figure 12B, we carried out growth curve analysis to the PTL_corr data by time bin.

Growth Curve Analyses

Finally, a two-level mixed-effects growth curve model with full information maximum likelihood estimation was carried out (Mirman, 2017). Linear, quadratic, and cubic temporal terms were modelled to estimate the slope, acceleration, and inflexions in the extremities of the pattern of fixations across time on trial. Orthogonal polynomial transformations for the time bins at the linear, quadratic and cubic terms were used to ensure that time on trial was orthogonal to each other and the correlations between time elevated to the different exponentials do not arise only due to the increase in numbering. For the GCA model interactions between the temporal terms (linear, quadratic, and cubic) by learning conditions (phonologically rel., phono-semantically rel., semantic rel., and unrelated), and by test block (first, second) were included as fixed effects. *Participants*, *test blocks* and *target labels* were added to the model as random effects; and were nested within the linear, quadratic, and cubic temporal terms to capture the variance associated with each participant at acceleration, the central and extremities curve inflexions on PTL_corr throughout the trial. The levels of the categorical factors were assigned as in the GLM model (see section "Generalised mixed effect model"). The resulting time course model model's lmer syntax was: PTL_corr ~ (poly1 + poly2 + poly3) * blockSum * Condition + (poly1 + poly2 + poly3 | subject) + (poly1 + poly2 + poly3 | blockSum) + (poly1 + poly2 + poly3 | targetSum)

Figure 16

Growth curve analyses model fit of baseline-corrected target looking.



Note. GCA model fit (lines) of the baseline-corrected target looking (shapes = means; error bars = standard error) for each time bin in the first (solid lines) and second (dashed lines) test block. GCA model fits for each learning condition: A) phono-semantically related, B) phonologically related, C) semantic related, and D) unrelated.

Model fits to the PTL_corr data are depicted in Figure 16. To follow, only the results were either learning condition or test block was significant will be described (for the full GCA model output, see Appendix U).

Phonologically vs. Phono-Semantically Related Learning Condition (Comparison 1)

The GCA model (κ = 6.29 and VIF = 4.54) parameter estimates revealed a significant interaction between test block and learning condition, comparison 1 at the linear temporal term. This indicates differences in the slope of PTL_corr curves between the phono-semantically and the phonologically related learning conditions across test blocks. Together with the visual inspection of Figure 16 (panels A and B), this suggests that the speed to recognize the novel target was faster in the phonologically related than in the phono-semantically related learning condition. Also, indicates faster novel target recognition in the first than in the second test block in both learning conditions.

Semantic vs. Phono-Semantically Related Learning Condition (Comparison 2)

In addition, the GCA model parameter estimates showed the significant effect of learning condition, comparison 2 at the quadratic temporal term. This indicates that the overall central inflexion of the PTL_corr differed significantly between the semantic and the phono-semantically related learning condition. Suggesting that novel target recognition was more accurate in the semantically related than in the phono-semantically related learning condition, as we can see in Figure 16A and 16C. Furthermore, the model revealed the significant interaction between test block by learning condition on comparison 2 at the intercept, linear and quadratic temporal terms. Indicating that the differences in PTL_corr also occurred when comparing the first and second test blocks. Pointing out that novel target recognition was more accurate in the semantically related condition in the second than in the first trial test block (see Figure 16C). While in the phono-semantically related condition were no differences between the first and second test block (see Figure 16A).

Phono-Semantically Related vs. Unrelated Learning Condition (Comparison 3)

The GCA model also revealed a significant interaction between test block and learning condition, in comparison 3 at the intercept and cubic temporal terms. Thus, pointing to differences in the overall height and extremities inflexions of the PTL_corr curves when comparing the first and second test blocks in the phono-semantically related and unrelated learning conditions. Together with the visual inspection of Figure 16A and 16D, this suggests that overall PTL_corr was higher in the unrelated than in the phono-semantic related condition. Also, indicates that novel target recognition in the unrelated condition was more accurate towards the end of the trials on the first block than in the phono-semantically related condition.

Drop1 Analyses

Finally, the function drop1 was utilized to assess the contribution of each factor to the time-course model (GCA). These analyses revealed the significant interaction of the *linear temporal term* test block *learning Condition* (χ^2= 54.89, df = 3, *p* < .001) confirming significant differences between learning conditions by test block at the slope. This result implies that novel target recognition varied across test blocks on each learning condition.

In conclusion, the results of the GCA suggest that, among all learning conditions, novel target recognition was more accurate in the phonologically related condition, as indicated by the looking measures above zero on both test blocks. Indexes of word learning were also found in the semantic related learning condition, where an increase in target looking in the second test block relative to the first one occurred. On the contrary, impaired novel target recognition was found in the phono-semantic related and unrelated learning conditions. In the former condition, as indicated by looking below zero in both test blocks; and, in the latter condition, as indicated by the decrease in target looking from first to the second test block.

V. Discussion

The goal of this study was to examine the contribution of phonological and semantic overlap among novel label-referent associations on novel word recognition. Therefore, a between-subjects design was implemented, where 22-month-old toddlers were presented with one of four learning conditions (see Table 7).

Overall, the analyses of total target looking showed non-significant differences between learning conditions and by test blocks (GLM). However, the time-course analysis (GCA) revealed statistical differences in patterns of novel target looking across conditions and test blocks. The time-course analyses, thus, indicated higher target looking in the phonological and semantic related than in the phono-semantic related. In addition, novel target recognition decreased from the first to the second set of test trials, suggesting lower target recognition in the unrelated than phono-semantic related condition. Next, the results on each learning condition will be discussed in the following order: phonologically related, semantically related, phono-semantically related and unrelated. Finally, the overall limitations and strengths of the study will be summarized.

Phonologically Related Learning Condition

The analyses of corrected total looking time did not find an overall effect of the phonologically related condition when compared with the phono-semantically related condition (GLM) or with the unrelated condition (GLM pairwise comparisons). However, time-course analyses found a significant interaction between the test block and condition at the slope when comparing the phonologically related condition with the phono-semantic related condition (comparison 1 in the GCA). These results suggest that novel-target recognition was more accurate and faster (slope effect) in the first than in the second test block (as suggested in Figure 16B). The time-course analyses where target fixations between the phonological and the phono-semantically related condition were compared found differences on the slope across test blocks (see Figure 16A and 16B). Indicating that novel target recognition was faster in the phonologically than in the phono-semantically related condition. This result suggests better recognition of similar-sounding novel labels when their referents belong to different taxonomical categories than when they belong to the same category.

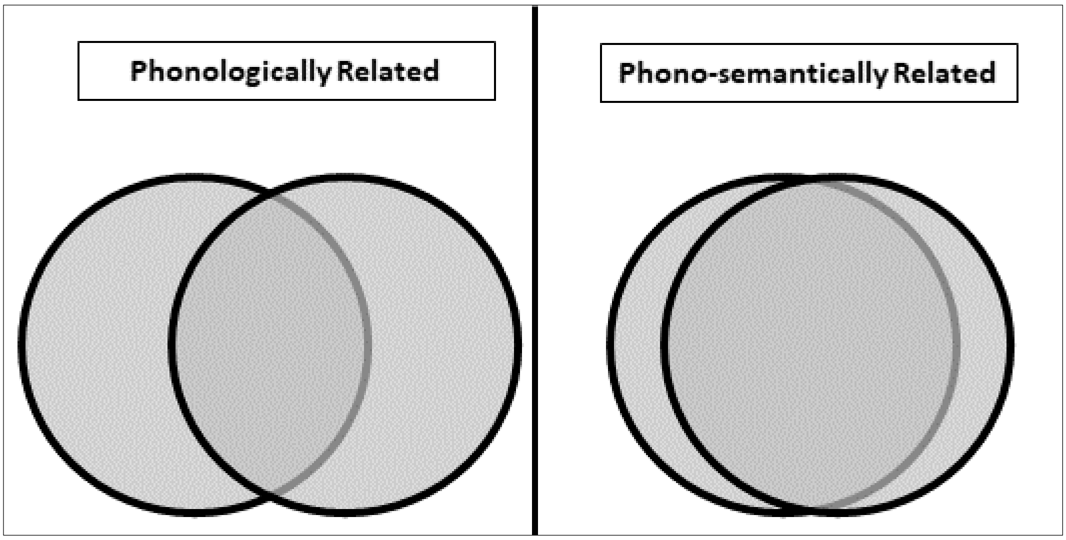
This result parallels previous studies that find that young children can learn phonologically similar pairs of labels when the referent belonged to different categories (Fennell & Waxmann, 2010; Yoshida, Fennell, Swingley & Werker, 2009). For instance, Fennell & Waxman (2010) found that clarifying the novel label referent status supported the learning of similar-sounding words (e.g., /bin/ and /din/) of 14-month-old English-speaking children. In our study, we extend those results to an older age group (i.e., 22 months of age); to the German language; to a learning situation where the referent status of the novel label was provided by a video of an actress manipulating the objects and naming them; to disyllabic words; and a preferential-looking task, rather than a habituation paradigm, to assess word learning. Also, we replicate the results reported in Yoshida et al. (2009), where toddlers learnt similar sounding words. In their study, 14-month-old participants were taught novel similar-sounding words (e.g. /din/ and /bin/) on a habituation procedure, yet word learning was tested applying a preferential-looking paradigm (i.e., displaying simultaneously both novel objects and naming only one of them). In particular, as in Yoshida et al. (2009), we found that target looking was highest in the first half of test trials (as suggested by Figure 16B).

However, our results differ from the results on Nazzi (2005), where 20-month-old toddlers showed better learning of novel words that sounded different (e.g. /pize/ and /mora/) than similar to each other (e.g., /pize/ and /tize/). This difference in results might be that in Nazzi´s (2005) study, they introduced feedback during a training phase before the learning testing phase, and we did not. Thus, although our task required less cognitive effort from the participants (as they had to passively look at the images) and in Nazzi´s study, children should choose the correct referent for the label; the lack of feedback in our study might have made it difficult for children to learn the novel label-referent associations.

The theoretical implications of the better novel target recognition on the phonologically alone related condition than in the phono-semantic related condition will be integrated into the framework of the LEX model of word learning (Regier, 2005). The LEX model predicts that learning on phonological o semantic alone conditions will be easier than in phono-semantic related conditions, which is supported by the results in the GCA. According to the LEX model, selective attention is at play to discriminate among similar word forms and meanings based on the significant differential aspects of the novel associations. In this case, novel target recognition is higher in the phonologically related condition because attention was selectively directed towards the non-overlapping semantic aspects. See Figure 17 for a graphical illustration, where it is suggested that the novel words in the phonological condition can be better discriminate among one another than words in the phono-semantic condition.

Figure 17

Graphical depiction of the discriminability of the novel label-referent associations in the phonologically related condition in comparison with the phono-semantic related condition.



Note*. The intersections represent the amount of overlapped information between the novel label-referent associations. In the phonologically related condition, the semantic information, i.e., categories "food" and "musical instrument", helps to discriminate among the novel concepts to be learnt. While in the phono-semantic related condition, the shared form and meanings difficult the discrimination between concepts.*

Semantic Related Learning Condition

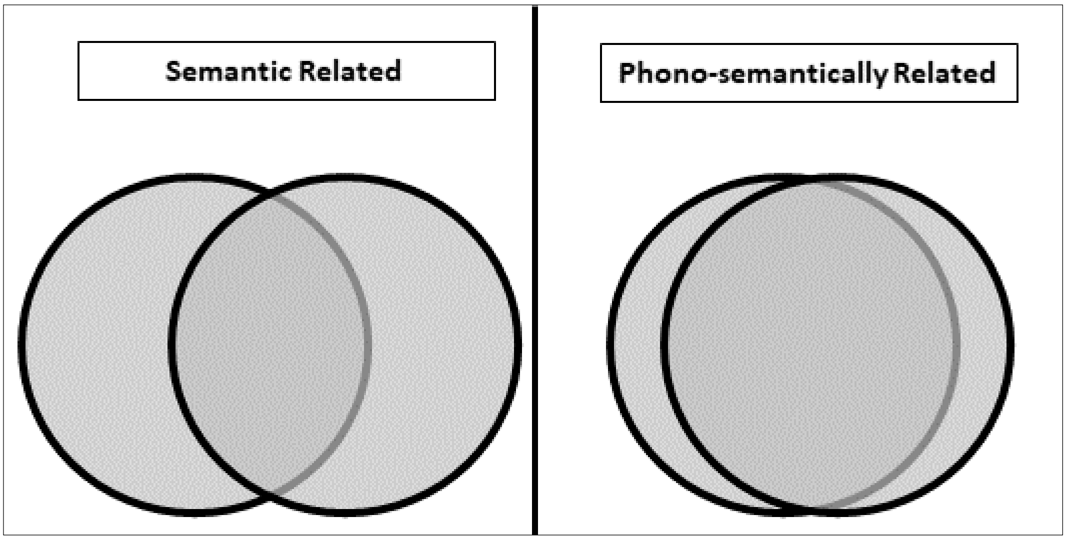
The total looking time analysis (GLM) does not show differences in novel target recognition across conditions or test blocks, but time-course analyses do. Namely, in the GCA analyses, there was evidence of a significant interaction between condition at the quadratic temporal term and between condition and test block (at the intercept, linear and quadratic temporal terms), suggesting that novel target recognition in the semantically related condition improved towards the second half of the study (see Figure 16C). It also indicates that when referents belonged to the same category (i.e., "food"), novel target looking was higher when the label sounded dissimilar (/simi/ and /alku/, see Figure 16C) than when they sound similar to each other (/simi/ and /sinqa/, see Figure 16A). That result parallels previous research on the encoding of category membership in target recognition (Borovsky et al., 2016a, 2016b; Peters et al., 2021) . For instance in the research of Borovsky et al. (2016a), where the authors distinguished between categories of words to which 24-month-old children knew many exemplars (e.g., animals or body parts) and categories to which they usually known few exemplars (e.g., clothing or vehicles). Then, children were taught novel infrequent words which belonged to those categories. For example, "hedgehog" (category with plenty of familiar words); and "kimono" (category with few familiar words). Here, higher target recognition was found for novel words from categories with plenty exemplars, suggesting that recognition was leveraged from shared features on well-populated categories in the child lexicon.

Although the referents' category was "food" in the semantic and phono-semantic conditions, and usually, children know plenty of food nouns (Borovsky et al., 2016a); in the current study, novel target recognition was higher in the semantic than in the phono-semantic related condition. This results are aligning with some predictions of the LEX model of word learning (Regier, 2005).

The LEX model (Regier, 2005) proposes that selective attention is at play for word learning as it reduces interference in memory. Thus, selective attention helped to discriminate between concepts with shared meaning and different label forms in the semantically related condition. In addition, children's difficulties recognising the novel targets in the phono-semantic condition may be explained because the novel label-referents associations presented did not provide enough cues to discriminate between novel concepts. Thus, the mechanism that may explain the results found in the semantically related condition (and as suggested for the phonologically related condition) may have been a general cognitive process in which available information from different sources is used to discriminate specific words associated with given meanings. Thus, we suggest that the differential phonological form of the labels in the semantically related condition contributed to discriminate between concepts, while in the phono-semantic condition the overlap in form and meaning prevented the discrimination between concepts. See Figure 18 for a graphical description of this explanation.

Figure 18

Graphical depiction of the discriminability of the novel label-referent associations in the semantic related condition in comparison with the phono-semantic related condition.



Note. The intersections represent the amount of overlapped information between the novel label-referent associations. In the semantically related condition, the phonological information, i.e., the different phonemes in the labels "simi" and "alku", helps to discriminate among the novel concepts to be learnt. While in the phono-semantic related condition, the shared form and meanings difficult the discrimination between concepts.

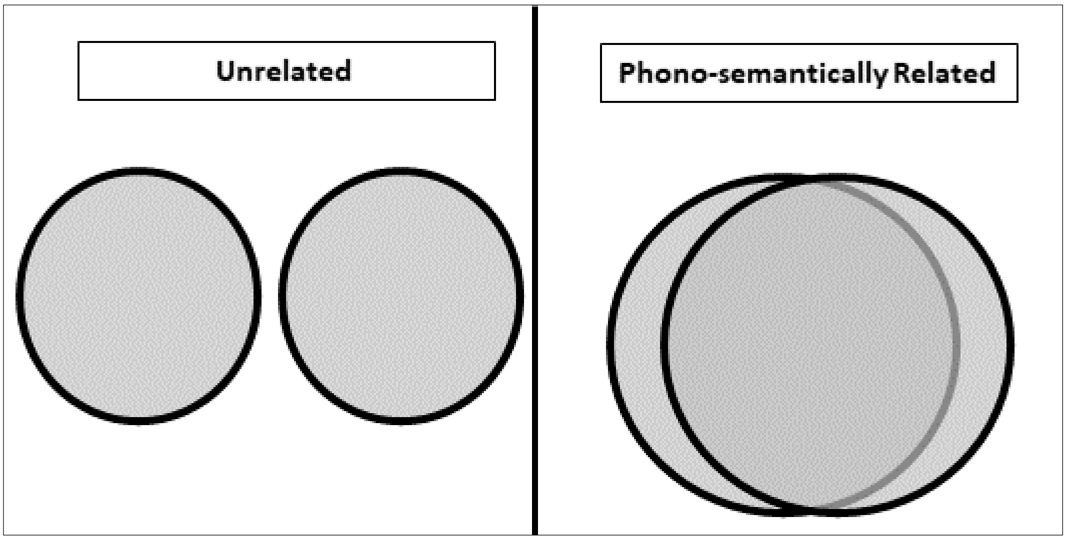
Unrelated Learning Condition

Regarding the unrelated condition, only the time-course analyses (GCA) found a significant interaction between condition and test block (at the intercept and cubic temporal terms). It suggests that in the unrelated condition (where the form and meaning of the novel words did not overlap), target recognition decreased from the first to the second test trial (see Figure16D) in comparison to the phono-semantic condition. This result, suggest that novel target recognition was better in the phono-semantic related condition than in the unrelated condition.

We partially replicate the results of a study of category learning Twomey et al. (2014), where it was found that high levels of within-category variability impaired word learning. Specifically, in Twomey et al. (2014), two-year-old children were presented with referents that belonged to novel categories (e.g., /duff/, /cheem/ and /hux/); and the authors manipulated whether, during the learning phase, participants encounter the same exemplar for that given category ("single" exemplar condition) or saw multiple exemplars that varied in colour ("multiple" exemplars condition). While novel labels from both conditions were learnt, after a brief delay, only the children exposed to the "multiple" exemplars condition remembered the novel labels. The degree of variability among the exemplars in two conditions was manipulated in a second experiment. In the "low" variability condition, exemplars varied in colour (e.g., red, yellow); and in the "high" variability condition, the exemplars varied across colour and another feature (e.g., shape, number of parts). In this case, again, while all novel labels were learnt, only participants exposed to the "low" variability condition remembered the labels after a delay. Indicating that while some variability among the exemplars that belong to the same category (as in the phono-semantic related condition) may support word learning when such variability is excessive, word learning is prevented (as in the unrelated condition). Therefore, the lower target recognition in the unrelated than in the phono-semantic condition could be caused by the excessive non overlapped information in the unrelated condition (i.e., different labels and categories). For a depiction of this reasoning, see Figure 19.

Figure 19

Graphical depiction of the discriminability of the novel label-referent associations in the unrelated condition in comparison with the phono-semantic related condition.



Note. The intersections represent the amount of overlapped information between the novel label-referent associations. In the unrelated condition, there was no overlapped phonological (different word forms, i.e., "simi" and "alku") or semantic information (each referent belong to a different category); thus, no shared features leveraged the learning of novel concepts; while in the phono-semantic related condition, the shared information supported the recognition of novel targets.

These results of lower novel target recognition in the second block of test trials in the unrelated condition (relative to the phono-semantic related condition) suggest that recognition was worst in the unrelated than un the phono-semantic related. Although, these results do not match the predictions of the LEX model, which would have predicted better learning in the unrelated condition than the other ones). However, these results align with the leveraging account for word learning, which states that shared features between familiar words and novel words to learn support learning. The absence of shared phonological and semantic features between the novel words to learn in the unrelated condition did not allow children to support learning.

In addition, these results match with the Distributed Cohort Model of spoken word recognition (Gaskell & Marslen-Wilson, 1997). According to the Distributed Cohort Model, phonological and semantic codes of words support recognition by reducing the distributed activation of related (yet not intended) word candidates. Better word recognition is expected in cases where shared phonological and semantic aspects are present than absent (such as in the unrelated condition).

Overall Limitations and Strengths of the Study

Next, some limitations on the current study will be mentioned. The principal concern is that we only find evidence of novel target recognition on the time-course analyses (GCA) but not on total time looking analyses (GLM). One reason for this can lie in the nature of looking behaviour, which changes as the trial unfollows. Thus, when we aggregate the fixation data across the entire analysis window, an initial increase on fixations at the target can be cancelled out by a later disengagement with the target picture; thus, neutralizing differences against chance level on analyses of total looking.

Another limitation in the current study is that one can argue that the results in the phonologically related and in the unrelated condition may have arisen from the particular categories used here, namely “food” and “musical instrument”. Given that typically, by 22 months of age, children are familiar with more nouns in the category “food” than for the category “musical instrument”. This can be an issue if we consider that previous research has found that novel word recognition is more accurate if the novel label designates a new item for a category for which participants already know plenty other exemplars (e.g., animals) than for a category for which they know few other exemplars (e.g., clothing items) (Borovsky et al., 2016a). However, the results on the GCA found better novel target recognition in the phonologically related than in the phono-semantically related condition (with referents from the “food” category, from which children knew plenty of words). Therefore, indicating that the specific categories used in the current study do not account for the results found. In addition, no significant correlations between the number of nouns and verbs familiar to children for the categories “food” and “musical instrument” with the proportions of target looking was found (ps > .491). Nor an effect of receptive or productive vocabulary size were found (ps >.742) 13. Thus, future research could explore whether these results could be replicated when children are taught novel labels that belong to different “highly” familiar categories (e.g., “food” and “animal”). This will provide more information about the potential role of “highly” and “poorly” represented categories on the learning of similar-sounding words for young children.

Another limitation in the current study can be attributed to the particular objects used as referents; that is, one could argue that the blue object looks similar to an “eggplant”. However, only six participants were familiar with the German word “Aubergine” (Engl., eggplant); and the exclusion of their data from analyses replicated the results reported here14. Therefore, further

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[13] We included verbs in the estimation, given that the German vocabulary inventory (Frakis; Szagun et al., 2009) utilized do not contain nouns referring to musical instruments. The familiar words from the category “food” were *M* = 43.55 (range = 9-64), and from the category “musical instrument” were *M* = 5.42 (range = 0-8). Participants’ receptive vocabulary size was *M* = 373.17 (range =101-599) and their productive vocabulary was *M* = 150.16 (range = 6-498). Given the wide variability in the number of words in each category and in vocabulary size, all measures were normalized (range = 0-1) using the R package caret (Kuhn, 2008). Then Pearson’s correlations between them and PTL_corr (*r*s < .05) were calculated using the stats base R package (R Core Team, 2013). Along with the data and main analyses scripts, the scripts for the correlations are stored on the Open Science Framework at https://osf.io/ybxuk// (Avila-Varela, Hartmann & Mani, 2022).

[14] This analysis also can be found on the Open Science Framework at https://osf.io/ybxuk// (Avila-Varela, Hartmann & Mani, 2022).

research may try to replicate this study using different objects as novel referents for the novel target recognition task.

Finally, it will be highly recommended to include “filler trials”, i.e., trials where pictures of familiar objects are displayed side-by-side (e.g., the images of a “dog” and a “car”) and one of them is named (e.g., “Look at the doggie!”). The reason to include filler trials is that they will indicate participants that, they have to look at the referent of the heard label.

All these limitations considered; next, some of the strengths of the current study will be mentioned. First, in all analyses, the labels used as stimuli (/simi/, /sinqa/ and /alku/) were included as random effects on the statistical models, thus ruling out potential individual differences’ preferences for the labels as the explanation for the effects.

Second, possible visual interest bias towards one object among the another was controlled by using as a dependent variable the proportions of target looking corrected with the looking to each picture during the pre-naming phase (PTL_corr). This is important to assure that the fixation data included in the analyses do not reflect the mere visual preference for one or another object.

Third, the experimental manipulations implemented in the learning conditions presented in this study mimic, to a certain extent, naturalistic learning situations that toddlers can encounter in their daily life. For example, the phonologically related learning condition could mimic situations where parents read poems or sing songs to children (in which children hear similar-sounding words in succession). The semantically related learning condition can simulate situations in which, in a given context (e.g., supermarket or breakfast), people start naming objects present in that context (e.g., apple, coffee). The phono-semantically related condition can simulate a game in which adults and children agree to name objects, according to certain rules, for example, to name things that start with the same sound and belong to the same category (e.g., face, finger, foot). Finally, the unrelated condition also may simulate playing situations in which labels with different forms belonging to different categories are said (e.g., plane, spoon, milk). Thus, the contribution of the current study to our understanding of the role of phonological and semantic features on novel target recognition is highlighted by the learning conditions presented, as they simulate learning situations that young children may encounter in their daily routines.

V. Conclusions

The current study examined the role of phonological and semantic features on word learning in young children. Therefore, 22-month-old monolingual toddlers were presented with a learning condition where novel labels shared the initial syllable or referents belonged to the same category.

The results show that novel target recognition was higher in the phonological or semantic alone related condition than in the phono-semantic related condition. These results are in line with the predictions of the LEX model of word learning (Regier, 2005), which suggest that the learning of words phonologically only or semantically only related will be better than words related phono-semantically.

The mechanism underlying this is the selective attention allocated to the codes that help to discriminate between concepts. Namely, in the phonologically related condition, attention to the different categories of the referents and the semantically related condition towards the non-overlapping form of the labels.

The results also show a relative better target recognition when words shared phonological and semantic aspects relative when the novel words had no phonological or semantic overlap, contradicting a prediction of the LEX model. According to the LEX model, the more dissimilar the words, the better their learning, and we found the opposite effect. However, this is in line with the Distribute Cohort Model of spoken word recognition (Gaskell & Marslen-Wilson, 1997), suggesting that words' phonological and semantic codes contribute simultaneously to recognition.

Thus, according to the Distributed Cohort Model, target recognition should be better for phono-semantic related words than unrelated words, as the shared overlap narrow down the number of other possible candidates for recognition. Higher target looking in the phono-semantic than in the unrelated condition is also in line with the leveraging account of word learning, which proposes that shared features between the novel labels learn and familiar words supports learning. In this case, the lack of shared codes in the unrelated condition makes it difficult for children to leverage based on semantic or phonological information.

V. Acknowledgements

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V. Author Contributions

D.S.A-V. and N.M. developed the concept for the study. Testing and data collection were performed by D.S.A-V and T.H. Data analysis was performed by D.S.A-V. and N.M. The manuscript was written by D.S.A-V and was revised by N.M. All authors approved the final version of the manuscript for submission.

V. Appendix S

Output of the generalized mixed effect model including the fixed effects of learning condition and test block for the baseline-corrected proportions of total target looking.

	Estimate	SE	*t*-value	*p* (>|t|)
Intercept	0.0015	0.026	0.058	0.953
Learning condition: Comp. 1	0.0311	0.037	0.850	0.395
Learning condition: Comp. 2	0.0031	0.037	0.084	0.933
Learning condition: Comp. 3	0.0394	0.038	1.026	0.305
Test block (first vs. second)	-0.0181	0.026	-0.695	0.487
Learning condition Comp. 1 by test block	0.0380	0.036	1.049	0.294
Learning condition Comp. 2 by test block	-0.0177	0.037	-0.477	0.633
Learning condition Comp. 3 by test block	0.0332	0.038	0.873	0.383

Note: For the comparison of the categorical levels in the learning condition, Comp. 1 refers to the *phonologically* vs. the *phono-semantically* related condition.; Comp. 2 is the *semantic* vs. the *phono-semantically* related condition; and Comp. 3 is the *unrelated* vs. the *phono-semantically* related condition.

V. Appendix T

Output of the comparisons between learning conditions for the baseline-corrected proportions of target looking.

	Estimate	SE	*t*-value	*p*(>|t|)
(Intercept) Unrelated vs. Phonologically related	0.0083	0.0377	0.22	0.826
(Intercept) Unrelated vs. Semantic related	0.0363	0.0386	0.938	0.348
(Intercept) Unrelated vs. Phono-semantically related	0.0015	0.0263	0.058	0.953
Slope by Unrelated vs. Phonologically related	-0.0048	0.0374	-0.129	0.897
Slope by Unrelated vs. Semantic related	0.0509	0.0383	1.33	0.184
Slope by Unrelated vs. Phono-semantically related	-0.0181	0.0261	-0.695	0.487

V. Appendix U

Output of the growth curve analyses models including the fixed and interaction effects of all temporal terms by condition and test block.

	Estimate	SE	*t*-value	p (>|t|)
Intercept	-0.0141	0.028	-0.513	0.608
Linear term	0.1788	0.134	1.335	0.182
Quadratic term	0.1116	0.089	1.257	0.209
Cubic term	0.0185	0.065	0.286	0.775
Test Block (first vs. second)	-0.0071	0.005	-1.306	0.192
Learning condition: Comp. 1	0.0699	0.038	1.842	0.065
Learning condition: Comp. 2	0.0300	0.039	0.763	0.445
Learning condition: Comp. 3	0.0470	0.040	1.183	0.237
Linear term by Test Block	0.1314	0.036	3.607	0.000***
Quadratic term by Test Block	-0.0144	0.036	-0.396	0.692
Cubic term by Test Block	0.0644	0.036	1.781	0.075
Linear term by Comp. 1	0.0840	0.179	0.470	0.638
Linear term by Comp. 2	-0.3148	0.185	-1.702	0.089
Linear term by Comp. 3	-0.2879	0.187	-1.541	0.123
Quadratic term by Comp. 1	-0.0724	0.111	-0.655	0.513
Quadratic term by Comp. 2	-0.3385	0.114	-2.970	0.003**
Quadratic term by Comp. 3	-0.0470	0.115	-0.408	0.683
Cubic term by Comp. 1	-0.0832	0.089	-0.938	0.348
Cubic term by Comp. 2	-0.0340	0.091	-0.373	0.709
Cubic term by Comp. 3	0.0521	0.092	0.566	0.571
Test Block by Comp. 1	0.0126	0.008	1.637	0.102
Test Block by Comp. 2	-0.0404	0.008	-5.226	0.000***
Test Block by Comp. 3	0.0290	0.008	3.712	0.000***
Linear term by Test Block by Comp. 1	-0.137	0.051	-2.676	0.007**
Linear term by Test Block by Comp. 2	-0.3055	0.052	-5.927	0.000***
Linear term by Test Block by Comp. 3	0.0428	0.052	0.822	0.411

Quadratic term by Test Block by Comp. 1	0.0414	0.051	0.811	0.418
Quadratic term by Test Block by Comp. 2	0.1021	0.051	1.987	0.047*
Quadratic term by Test Block by Comp. 3	0.0798	0.052	1.535	0.125
Cubic term by Test Block by Comp. 1	-0.0910	0.051	-1.791	0.073
Cubic term by Test Block by Comp. 2	-0.0458	0.051	-0.895	0.371
Cubic term by Test Block by Comp. 3	-0.1058	0.052	-2.040	0.041*

Note: For the comparison of the categorical levels in the learning condition, Comp.1 refers to the *phonologically* vs. the *phono-semantically* related condition; Comp. 2 is the *semantic* vs. the phono-semantically related condition; and Comp. 3 is the *unrelated* vs. *the phono-semantically* related condition. Signif. codes: 0.001 '***' 0.01 '**' 0.05 '*'

Chapter VI. General Discussion

A plethora of research has shown that phonological (words' form) and semantic (words' meaning) are encoded during speech processing (Huettig & McQueen, 2007; Chow et al., 2017). The priming paradigm is a relevant experimental setup implemented to study the impact of word overlap on processing. Under this paradigm, it is typically assumed that differences in target recognition when previously a related or an unrelated word was presented is an indicator of the links between words in the mental lexicon. The study of this organization, specifically uncovering the links between words, is important since it tells us how the stored knowledge interacts with the online processing of familiar words and how it affects the learning of new words.

Two widely studied overlaps between words are the phonological (words' form) and the semantic (words' meaning) relations. For instance, previous studies with adults and children reported priming effects on the recognition of words when similar sounding words or words belonging to the same category were previously presented (Slowiaczek & Hamburger, 1992; Meyer & Schvaneveldt, 1971, Arias-Trejo & Plunkett, 2009,2013; Mani & Plunkett, 2009, 2011). In addition, some research has suggested that the sensitivity to phonological and to semantic overlap between words might support word learning (Newman et al., 2009; Borovsky et al., 2016; Fourtassi et al., 2020; Storkel, 2006).

Given that frame, the current dissertation aimed at answering the following questions: (i) how does this modulation of word recognition based on phonological and semantic similarities among words vary across development? (ii) Does the single overlap between words affects combined recognition differently than combined overlap? (iii) Does phonological and semantic overlap between words affects word learning?

Specifically, Study I in this dissertation (Chapter III) aimed at determining the role of vocabulary size on phonological and semantic priming effects for the recognition of familiar words. Study II (Chapter IV) was carried out to explore whether the combined sources of overlap (phonological and semantic simultaneously) impacted differently the recognition of familiar words than single priming (i.e., either phonological or semantic alone). Finally, Study III (Chapter V) compared the role of single versus combined sources of overlap in novel word recognition.

In this dissertation, Study I found the first evidence demonstrating the effect of children current vocabulary size on phonological interference. Study II found a reduced interference in combined phono-semantic overlap than in phonological overlap alone; in contrast, Study III found better novel target recognition under simple overlap (phonological or semantic) than compound overlap. Together from results of Studies I, II and III, it can be concluded that phonological and semantic overlap between words alone or in combination impacts differently familiar and novel word recognition. In general, interference effects are mediated by children current vocabulary (Study I) and age (Study II), indicating that children activate related phonological and semantic related words during speech processing that remain active after hearing the target, leading to interference in recognition. On the other hand, in novel word recognition, the partial overlap between words offers enough cues to discriminate among novel concepts to support novel word recognition (Study III). Further research should aim to disentangle the role of vocabulary size and of other cognitive functions (e.g., selective attention and inhibitory control) on word recognition and word learning across development.

VI. A. Implications of Study I

Research on children's sensitivity to word overlap has found that young children showed facilitation in the recognition of words when phonologically related words are previously presented (Mani & Plunkett, 2010). However, those effects turned into interference when children are two years old (Mani & Plunkett, 2011). The transition from facilitator towards interfering effect of priming with phonologically similar words has been related with the increasing vocabulary size at those early ages. Regarding semantic priming, facilitation on word recognition have been reported in two-year-old children when they were presented with associative or taxonomically related words (Arias-Trejo & Plunkett, 2013). Additionally, backward semantic inhibition has been reported when an additional word is introduced in between two taxonomically related prime and target words (Chow et al., 2016). The presence of an unrelated word broke the processing of the semantic relatedness between the prime and the target words, thus generating an interference for the recognition of the target. More recently, backward semantic inhibition has been reported in toddlers of 18 months of age but with larger vocabulary size, thus indicating that those effects need a well-populated lexicon to arise. Previous research had already found a relationship between vocabulary size (e.g., Fernald & Marchman, 2012) and age on the speed and the accuracy of word recognition (e.g., Borovsky, Elman & Fernald, 2012). Nevertheless, the particular contribution of children's vocabulary size regardless of the participants' age on phonological and on semantic priming effects for word recognition had not been assessed.

Therefore, the first study in this dissertation carried out a longitudinal study in order to examine the roles of childrens’ vocabulary size and age for the recognition of familiar words in the context of phonological overlap, semantic overlap or no overlap between words.

Effects of current vocabulary on phonological interference

The main result of Study I is that the participant’s current vocabulary size could predict phonological priming effects, even after controlling for the participant’s age and early vocabulary size. This effect of vocabulary on the phonological link indicates that the more words form mental lexicon of a child, the more words are activated when a spoken word is heard, leading to an interference in word recognition. Thus, these results show that the children’s current vocabulary size is more important than children’s age to account for their sensibility to phonological overlap between words.

This observation fits well with previous studies in adults and children which suggested that the more similarly-sounding words a target has, the more competition occurs during recognition (Slowiaczek & Hamburger, 1987; Luce & Pisoni, 1998). On the contrary, younger children tend to show facilitation of word recognition if the two words presented are similarly-sounding (e.g. “dog”-“door”) (Mani & Plunkett, 2010a). Around 24 months of age, target recognition becomes more accurate if the words do not overlap phonologically (e.g., “plane”-“door”), in addition those interference priming effects were more accentuated when participants knew many other similar-sounding words to those presented (e.g., children knowing many other words sounding similar to “plane”, such as “plate” and “place”) (Mani & Plunkett, 2011). Thus, the results in Study I confirm previous speculations suggesting a turn from early phonological facilitation (at 18 months of age) to phonological interference in older children (Mani & Plunkett, 2010a, 2011) as the size of vocabulary increases with age. Younger children may know fewer similarly-sounding words and, therefore, less competition is triggered for word recognition during speech processing. As the child grows and her vocabulary increases, the more similar-sounding words enter the mental lexicon which could compete during word recognition.

Altogether, this can be interpreted as an additional evidence for the important relationship between children mental lexicon size (measured by her vocabulary size) and her online skills to process language (here, sensitivity to phonological similarities among words). The role of vocabulary can be claimed from this study as it had a longitudinal design where the same sample of participants was studied longitudinally (at 18, 21 and 24 months of age). This is especially important as it allows to control for additional sources of individual variability (e.g., other memory or cognitive skills) on word recognition.

While implementing Study I, the opportunity to replicate it on a sample of Spanish speaking children arose; from that collaboration with Prof. Natalia Arias-Trejo from the Universidad Autonoma de México, we recently published a study (Arias-Trejo et al., 2022). We replicate the vocabulary effects on phonological interference in word recognition found with German toddlers and add that the density connectivity of the vocabulary networks correlated with semantic facilitation. These results highlight that word recognition is determined by the mental lexicon size and the degree of connections between the words on it. These results align with research finding that children with better-connected vocabularies had faster vocabulary acquisition (Hills et al., 2009; Beckage et al., 2011).

Effects of semantic interference

The second main finding in Study I is that, when considering sensitivity of children to semantic overlap, participants looked more to the target when it was preceded by a semantically unrelated word. That is, toddlers showed evidence of semantic interference on word recognition regardless of their age and vocabulary size. These results are consistent with other studies on backward semantic inhibition in children of 24 months of age (Chow et al., 2016) and children with larger vocabulary size at 18 months of age (Chow et al., 2019); and with a study of head turn preference (Willits et al., 2013) in which children looked more to the target after presentation of an unrelated semantic prime.

Nevertheless, it is essential to notice that contrary to other studies reporting semantic facilitator priming effects on word recognition; that is, higher target looking (e.g., “dog”) when previously a semantically related item was presented (e.g., “cat”) than when an unrelated item preceded (e.g., “table”). Facilitation in target recognition was reported in 18-month-old children with larger vocabulary, at 21-months and 24 months of age (Rämä, Sirri & Serres, 2013; Rämä, Sirri & Goyet, 2018; Arias-Trejo & Plunkett, 2009, 2013; Styles & Plunkett, 2009). These contradictory results of semantic interference and facilitation might be due to differences in the timings of the experiments implemented. between the presentation of the prime and the target. While in Study I we implemented an interstimulus interval of 500ms, Arias-Trejo and Plunkett´s studies applied a 200ms interval. In line with this suggestion, a recent study testing phonological and semantic priming effects using an interstimulus interval of 200ms (instead of 500ms) on a sample of Spanish-speaking children aged 18, 21, and 24 months found semantic facilitator effects on target recognition (Arias-Trejo et al., 2022). Therefore, the difference in finding facilitation or interference might be related to a more automatic cognitive mechanism when the inter stimulus interval is short and a more controlled mechanism when the interval is longer (Hamburger & Slowiaczek, 1996).

Also, in Study I, semantic interference was not explained better by vocabulary size, a result that is consistent with previous studies of semantic preparation on word recognition measured with eye-tracking (Arias-Trejo & Plunkett, 2009, 2013; Styles & Plunkett, 2009). Although, this null effect of children's vocabulary size on semantic priming is inconsistent with studies measuring event-related brain potentials –ERPs–(e.g., Rämä, Sirri & Serres, 2013); or using the backward semantic inhibition paradigm (Chow et al., 2019). These differences may be the consequence of the differential measures and designs applied in each case.

VI. B. Implications of Study II

The activation of phonological and semantic codes has been studied in mediated-priming tasks showing facilitation in the recognition of phono-semantically related words children and adults (Huang & Snedeker, 2011; Marslen-Wilson & Zwitserlood, 1989; Altvater-Mackensen & Mani, 2013b). Other studies using the additive priming paradigm showed that presenting words with similar meaning lead to facilitation in word recognition in 2-years-old children (Arias-Trejo & Plunkett, 2013). However, a study of phonological priming effects alone found interference effects in word recognition when presenting phonologically related words to 2-years-old children (Mani & Plunkett, 2011).

Therefore, in Study II we investigated whether the combination of phonological and semantic overlap between words would reduce the phonological alone interference effects found when applying the additive priming paradigm. Specifically, in Study II, 22-month-old participants were presented with phonologically alone and phono-semantic related and unrelated pairs of words. This study compared priming effects on target recognition when single versus compound links were tested. Two types of statistical analyses were carried out: general linear mixed effect models (GLM) on total proportions of looking times and a growth curve analysis (GCA) on time-course changes of target fixations.

Reduced phono-semantic interference relative to phonological interference

The results for the total looking time only showed overall target looking differences by lexical type, higher in the phonological trials than in the phono-semantic trials. But the time-course analysis showed priming effects in both lexical links towards interference effects (i.e., higher target looking in unrelated than related trials). The main result of Study II is that, although interference effects were found when testing both phonological alone and combined phono-semantic overlap between words, there was higher target recognition under the combined link. Thus, concluding that the addition of the semantic overlap on top of the phonological overlap between words facilitated recognition.

Phonological interference

Study II also found phonological interference in word recognition in 22-month-old children as uncovered by the time-course analysis. This result confirms previous studies that found interference when children were presented with similar-sounding words (Mani & Plunkett, 2011) and with the results in our Study I in which phonological interference of word recognition in infants were modulated by children's current vocabulary size. However, it is important to note that in Study I the evidence of phonological priming was found in the total looking analysis, while in Study II the evidence for priming was only found in the fine-grained time-course analyses. These differences may have been driven by the experimental designs of the two studies: Study I is a longitudinal experiment while Study II was cross-sectional investigation. The longitudinal design might have imposed higher control over individual variability in terms of age and vocabulary than in the cross-sectional study, increasing the statistical power on the total looking time analysis of Study I.

Phono-semantic interference

Regarding the phono-semantic link, Study II found evidence for interference on based on the time course analyses while previous studies of mediated priming in 24- and 30-month-old toddlers showed facilitation in word recognition after the presentation of a phono-semantic related prime (Angulo-Chavira & Arias-Trejo, 2018; Mani et al., 2013). A reason for these differences in the trends of the priming effects could be driven by the two experimental tasks implemented. While in Study II an “additive” priming paradigm was implemented, in Angulo-Chavira & Arias-Trejo (2018) and in Mani et al. (2013), a “mediated” priming paradigm was implemented. In what follows, we will discuss the differences between both paradigms.

In the ***additive priming***, a prime (e.g. “turkey”) is followed by phonologically and semantically associated target words (e.g., “turtle”). In this example, the pair “turkey”- “turtle” share the initial CV /tɜː/, and both words refer to exemplars of the category “animal”. In contrast, ***mediated priming*** requires the activation of a mediator stimulus (related with the prime and associated with the target). For example, the presented prime “dog” which activates the semantic associate “cat” (as both belong to the same category “animal”), thus later when a phonologically related target to the mediator is presented, e.g., “cup” (i.e., “cat”-“cup”, share the onset /k/), their recognition is facilitated. Here, as there is no direct association between prime and target (“dog”-“cat”), facilitation in recognition occurs thanks to the activation of the mediator word following the presentation of the prime, which later pre-activates semantic related words, among which is the target. Thus the pre-activation of the target candidate by the mediator stimuli served to facilitate word recognition. Therefore, the phono-semantic interference found in Study II could have been driven by the activation of phonologically and semantically associated with the target. While the facilitation in Mani et al. (2013) and Angulo-Chavira & Arias-Trejo (2018) could have been driven by the activation of either semantic or phonologically associates to the mediator stimuli.

The contrasting results of the phono-semantic interference of Study II and the phono-semantic facilitation reported in the mediated priming studies (Mani et al., 2013; Angulo-Chavira & Arias-Trejo, 2018) could be due to the different number of processing stages involved in the two paradigms. Although phonological and semantic associated words are activated in both paradigms, in the mediated priming, such activation is sequential, while additive priming is simultaneous. Thus, in the mediated priming, in an initial stage of processing, words are activated based on a single link (e.g., phonological associates to the prime). In the second stage of processing, words associated with the mediator are activated based on another single link (e.g., semantic). Instead, in the additive priming, phonological and semantic associates to the target could be simultaneously activated. Therefore, dividing the processing into two steps might ease target processing in the mediating priming paradigm, thus facilitating target recognition. In comparison, the simultaneous presentation of combined phonological and semantic characteristics in the additive priming could have increased the cognitive costs of processing, thus leading to interference.

Along these lines, the difficulty of presenting combined phonological and semantic overlap words also could be seen in Study III of this dissertation, in which it was found lower target recognition in phono-semantic than in phonological or semantic alone related novel words. This result indicates that recognition was better when simple overlaps were presented than combined overlaps. The additive phono-semantic overlap could have been more difficult for young children to process in Studies II and III because children had to discriminate among highly similar words (i.e., in form and meaning).

In summary, the main implication of Study II is that the combination of phonological and of semantic domains on additive priming tasks to reduces interference effects on word recognition compared to simple phonological overlap.

VI. C. Implications of Study III

Considering the impact of phonological and semantic overlap on word learning has been found a leveraging effect on word learning. Specifically, it has been reported that children tend to learn words that sound similar to familiar words (e.g., Newman et al., 2008; Storkel, 2006) and that belong to semantic domains with already plenty of words (e.g., Borovsky et al., 2016b, Hills et al., 2009). However, when investigating the role of phonological overlap on learning, most studies on word learning have excluded the semantic overlap among referents (Nazzi, 2005). Similarly, studies investigating the role of semantic overlap have been carefully designed to prevent phonological overlap between the novel label from teaching to the participants (Wojcik & Saffran, 2013). In addition, only a few studies have investigated the effect of combining phonological and semantic overlap between novel label-referent associations (Twomey et al., 2014). Although those studies suggest that word learning is still possible, more research is required about the optimal combination of phonological and semantic domain overlap for learning. Thus, the Study III on this dissertation investigated the impact of words' overlap between form and meaning (in combination or separately) on novel word recognition.

Toddlers were taught one of four novel label-referent associations, where the two novel words were only phonologically related, only semantically related, phono-semantically related or unrelated. Although the results on total looking time did not show differences across learning conditions on novel target recognition, the time-course analyses showed differences in novel target recognition depending on the type of overlap of the words taught. Specifically, we found higher novel target recognition in phonologically or semantic related learning conditions than in the phono-semantically related one. These results show that novel target recognition was benefited from one source of overlap between the novel words—i.e., phonological or semantic—but not at both simultaneously. **These results demonstrate that children encode the similarities between familiar and novel words to learn and that they can rely on the dimensions among which they do not overlap to distinguish between them to support their recognition.**

Increased novel target recognition in simple than compound overlap

The result of better recognition of novel words overlapping only at the word-form than overlapping at the form and meaning is consistent with studies that found similar sounding words were learned by toddlers (Fennell & Waxman, 2010, Yoshida et al., 2009; Nazzi, 2005; Werker et al., 2002). Thus, the current work extended those findings to show that 22-month-old children can learn and recognize novel, similar-sounding words better when they belong to different semantic categories than when they belong to the same category. However, the result of better novel label recognition in phonological than phono-semantic related conditions is incongruent with a previous study that found that children had difficulties learning similar-sounding words (Stager & Werker, 1997). These different results may be related to the age of the participants and the methodologies implemented in the studies. Thus, it could be that the 22-month-old children tested in Study III had already developed attentional or memory skills to discriminate similar-sounding novel labels compared to the 14-month-old children tested in Stager & Werker (1997). In addition, the preferential looking task might impose higher visual demands as it displays two objects as potential referents for the heard label, while in the switch task used in Stager & Werker (1997), only one image is displayed, and one label (associated or not with the referent) is heard.

Concerning the better novel target recognition of semantically related than in the phono-semantically related condition, this result is consistent with previous research showing the effect of category density in target recognition by young children (Borovsky et al., 2016a, 2016b; Peters et al., 2021) and on category learning (Twomey et al., 2014). For instance, in Borovsky et al. (2016a, b), it was found that familiar and novel target recognition was faster and more accurate when the novel words belonged to categories to which children knew many other exemplars. Borovsky and collaborators explain the facilitator effects in novel word recognition as a semantic leveraging effect from what the child already knows to support the learning of novel items that fit well with previous knowledge. By their side, Twomey and cols (2014) found that presenting two-year-old children with different items facilitated learning novel categories labels. Therefore, the results in the semantically related condition in Study III extend those results showing that children successfully learn label-referent associations, when there is semantic overlap between the novel referents.

Increased novel target recognition in compound than in unrelated overlap

In Study III, novel target recognition was higher in the phono-semantic related condition than in the unrelated condition. These results are incongruent with what we found in Study II, i.e., reduced interference in familiar word recognition under phono-semantically overlap than in phonologically overlap alone. Namely, Study II find that while the compound phono-semantic link supports recognising familiar words, Study III finds that this compound link in comparison with a simple link hinders recognition. In contrast, phono-semantic overlap supported recognition of familiar words more than single phonological overlap, single phonological or semantic overlap supported novel word recognition more than phono-semantic overlap. Together these results highlight the differential role of combined and single overlap between words on recognising familiar and recently acquired words.

The result of higher novel target recognition in the phono-semantic than in the unrelated condition is congruent with the results found in Twomey et al. (2014) that showed that high levels of within-category variability impaired word learning. Specifically, in Twomey and collaborator's (2014) study, 2-year-old children were presented with a task where different objects belonged to a given category (e.g., "doff"-"chem"). In this study, the authors found that while children learnt the novel category names when the referents were different in one dimension (e.g., colour), it also was found that when the items were different in many dimensions (e.g., colour and shape), learning of the novel category labels were impaired. Twomey et al. (2014) could relate to the unrelated learning condition in Study III as referents varied across multiple domains (i.e., category, shape, colour), thus it could have been too complicated for children to learn and recognise the novel associations.

Overall, the implications of the results in Study III are that overlap in form alone (i.e., phonological overlap) or meaning alone (i.e., semantic overlap) supports novel word recognition, thus highlighting some practical advice on teaching techniques. Our results show that situations in whch novel words overlap only phonologically or only semantically benefit their later recognition. Hence, a learning context where the phonological overlap is salient, such as in the contexts of teaching through musical sonority, story tales with rhymes or poems; or where novel concepts to learn are presented in categories (i.e., novel animals by one part, and novel vehicles) may be recommended to support novel label recognition in children. Also, it could be advised to avoid situations in which novel words overlap both phonological and semantically as it will be hard for young children to distinguish between words.

VI. D. Implications of the thesis for models of lexical access

The phonological interference effects related to vocabulary size reported in Study I, and the phonological interference found in the relatively older children tested in Study II fits well with the predictions of the Cohort Model (Marslen-Wilson & Tyler, 1980; Marslen-Wilson & Welsh, 1978) and the Neighbourhood Activation Model (Luce & Pisoni, 1998) of speech recognition.

According to the Cohort Model (Marslen-Wilson & Tyler, 1980; Marslen-Wilson & Welsh, 1978), spoken word recognition occurs in three stages: access, selection and integration. In the access stage, acoustic-phonetic elements at the onset of words in the speech are aligned with words in the lexicon, activating a set of candidate words. Later, during the selection stage, candidate words that mismatch the incoming speech are rejected for recognition. During the integration stage, top-down sentential syntactic and semantic can also induce the rejection of pre-activated candidates in the initial set. Thus, the Cohort Model (Marslen-Wilson & Tyler, 1980; Marslen-Wilson & Welsh, 1978) can account for the vocabulary effects on word recognition found in studies one and of age in two; as the more words a child knows, the more candidate words could be activated during the stage of access describes in the model. Thus, the lower the vocabulary a participant has, the lower the number of competing candidates are activated when the prime and target are presented, thus leading to facilitator effects in word recognition. On the contrary, the more words a child's lexicon has, the higher the number of competing candidates active for recognition when the prime and target are presented; this could lead to interference effects in word recognition. Altogether, the results in Study I of phonological priming modulated by current vocabulary size support the assumptions that the more words a child knows, the more words are activated for recognition, being this more important than their age and previous vocabulary.

Furthermore, according to the Neighbourhood Activation Model (NAM, Luce & Pisoni, 1998), the speech input is assumed to activate a set of words (stored as acoustic-phonetic patterns) that minimally differed from the input (by one phoneme through deletion, addition or substitution). A difference with the Cohort Model, which prioritizes the initial onset of words to activate a set of candidate words, the NAM considers the frequency of the similar-sounding candidates for word recognition. Thus, the Neighbourhood Activation Model predicts interference effects on word recognition, for words with many similar-sounding words, and with high frequency; and facilitation in the recognition of words with few similar-sounding words and with low frequency. Those predictions align with the vocabulary size modulation effects on phonological interference found in Study I; and the phonological interference effects were found in relatively older toddlers found in Study II.

The result of semantic interference found in Study I and of the reduced phono-semantic interference relative to the phonological interference, found in Study II will be framed on the Distributed Cohort Model (DCM, Gaskell & Marslen-Wilson, 1997). In this case, the Cohort Model and the NAM will not be considered because those models attribute crucial importance to the acoustic-phonetic patterns of words while relegating the importance of words meaning during word recognition. According to the DCM, there is a direct mapping from phonetic features onto distributed abstract representations of both words forms (acoustic-phonetic features) and meaning (semantic or syntactic related aspects of the word meaning). The DCM has an input layer that takes binary phonetic features as input. For example, if the sound heard is /n/, the “Nasality” feature gets a 1, otherwise a 0. Connected to the input layer is a hidden layer connected to two output units, one for phonological features and one for semantic features (see Figure 3). Thus, the phonological output contains nodes representing information about the phonemes in a word, and the semantic output contains nodes representing information about the meaning of the words. In the DCM, there is no direct mapping between a word and a “node” or element for recognition. Instead, lexical units are points in a multidimensional space, represented by a vector formed by a blend of nodes from the phonological and semantic output. Thus, speech recognition is a direct and continuous map process, in which as more speech input is available, the network gets closer in the lexical space corresponding to the presented word. Here, word activation is inversely related to the distance of the model output and the target word representation in the lexical space. The number of candidate words mediates competition in the DCM; the higher the number of possible candidate words for recognition, the lower their activation level. As acoustics features are the first to be perceived, phonologically associated candidates are mainly activated based on similarities in sound, while semantic information starts as a blend of the semantic vectors of all words in the lexical space. Later, as more acoustic information is available, the blend of semantically matching candidates is reduced until one single word is left. Therefore, one of the predictions of the DCM is that in cases of phonological ambiguity (different words with similar word beginnings), semantic information can narrow down the set of candidates activated for recognition by reducing the distributed activation of candidates that do not match with the semantic context. For example, the possible candidate word “garment” will have higher activation upon hearing their initial sounds (e.g., /gɑːm/) as in English mainly can be completed for that word; therefore, the network phonological and semantic outputs increase the activation of “garment” for recognition above other words. While in the case of hearing an initial onset (e.g., /bɑː/) that can be completed with many options (e.g., “bath”, “basket”), network output has distributed the activation all these possible associates as both are phonologically and semantically plausible. However, if the syntactic or semantic context of the sentence in which the word is presented suggests only one meaning (e.g., “talking about buying at a grocery store"), then for example, the word “basket” will increase their activation.

In Study I, a consistent semantic interference effect in word recognition was found, independent of participants' receptive vocabulary size and age. That is, overall, participants showed a better target recognition (e.g., "duck") when previously an unrelated semantic word (e.g., "spoon") than when a semantically related word (e.g., "monkey") was presented. The DCM account for the semantic interference effects found in Study I, if we consider that the shared semantic information between prime and target (e.g., "monkey"- "duck", both "animals") maintained higher activation across multiple lexical candidates belonging to the same category of the target. The semantic overlap between prime and target could have hindered word recognition, as there are many semantic plausible candidates with shared semantic activation. In addition, the relative reduction in target interference under phono-semantic overlap than in only phonological overlap found in Study II align with the predictions of the DCM that suggest that the added semantic overlap supported recognition by reducing the distributed activation of semantically unrelated words.

One of the contributions of this dissertation to models of word recognition was to provide evidence demonstrating the critical role of children's current vocabulary size on phonological interference even more than age or early. Thus, supporting some model assumptions that phonological and sematic related words are activated and compete for recognition during speech processing; as we found that indeed the more words a child knows more phonological interference in word recognition they show (Study I), and also when they are relatively older (Study II).

In addition, the systematic interference effects found on word recognition when presenting semantically related, phonologically related and phono-semantic related words; might indicate that during toddlerhood, the presentation of related words hinders word recognition. Thus, these results contribute to models of speech processing on suggesting that when presenting related words (independently of age and vocabulary size), at younger ages are difficulties in reducing the activation of semantic associates of words after the complete target word is heard. The work on the current thesis suggests that the interference effects found are driven by children not having fully developed efficient inhibitory links to suppress the activation of competing related candidates to the target pre-elicited by the prime. This suggestion is in accordance with the developmental approaches, which consider that attention and control superior executive functions need years to develop fully (e.g., Fiske , 2019; Mehnert et al., 2013 also see Mayor and Plunkett, 2014, for a computational implementation of inhibitory processes in the infant lexicon).

VI. E. Implications of the thesis for models of word learning

Word recognition and word learning are tightly interconnected processes, given that for learning a new word, first, one needs to know that word is not already stored in memory. However, in infancy literature, it is still under debate when a child "properly" learns a word, given that at younger ages, infants encounter words for the first time, thus learning something new about them on each encounter. The results of this dissertation on the effect of simple (phonological and semantic) and compound overlap between words impact differently the recognition of familiar and recently acquired words. Namely, while study two found reduced interference effects on familiar word recognition when the combined overlap between words was presented in comparison to simple overlap; Study III showed the reverse effect, i.e., novel target recognition was higher under single than compound overlap. **Thus, the main contribution of Studies II and III is to provide additional evidence suggesting that the role of phonological and semantic alone overlap and compound phono-semantic overlap impacts differently the recognition of familiar and recently acquired words, and ultimately indicates that words overlap impacts differently word recognition and word learning.**

Regarding models of word learning, the results of Study III will be discussed in the frame of the LEX model (Regier, 2005) of word learning. The LEX model (Regier, 2005) is a model for word learning based on computational simulations in which the phonological (i.e., word form) and semantic (i.e., meaning) aspects of words are considered. This model proposes that the crucial mechanism in play for young children's growing ability to learn new words relies on selective attention to relevant aspects of word forms (e.g., phonemes) and meaning, which reduces memory interference. According to this model, for a given word form, the model produces a probability distribution over associated referents (i.e., exemplars of similar meaning); and vice versa, given a referent, the model produces a probability distribution over associated exemplars of similar form. These associations are mediated by a single set of associative links, connecting the two hidden layers of the model (see Figure 5). Form exemplar nodes and meaning exemplar nodes are associated one to one through associative weights. Additionally, there are also weights encoding selective attention to each dimension of form (e.g., for phonetic features such as voicing or pitch that helps to discriminate among minimally different words as "pat" and "bat") and each significant dimension of meaning (e.g., shape or colour that helps to differentiate referents belonging to the same category). The weights encoding selective attention stretch and compress word forms with clusters of meanings. When a novel word or referent is presented, no other exemplars will be near (in the form or meaning space) because the novel word by definition differs from other words along significant dimensions, thus reducing interference with other similar forms or meanings. The LEX model has some predictions concerning similarities in word form and meaning, i.e., word learning will be easier when words do not overlap in form or meaning, followed by words that partially overlap in form or meaning, and words that overlap in form and meaning will be maximally difficult to learn.

The results of Study III found that according to the predictions of the LEX model (Regier, 2005), novel word recognition was higher in the simple overlap conditions (i.e., phonological or semantic overlap) in comparison to the compound overlap (i.e., phono-semantic overlap). Thus, these results suggest that aligned to the proposal of the LEX model, the increase in discriminability among partially related concepts benefited word learning compared to concepts related in form and meaning. Thus our study contributed to testing the hypothesis presented in the LEX model.

However, and contrary to the hypothesis of the LEX model, novel target recognition was better when words were related in form and meaning than when they were unrelated. Thus, indicating that the high dissimilarity between novel concepts hindered novel word recognition. Although those results do not confirm the hypothesis of the LEX model, they can be explained under the levering account for word learning. The leveraging account suggests that children’s previous knowledge of semantically related words can support learning novel words of similar meaning by the semantic similarities between a novel word and pre-existing mental representations of words stored in the mental lexicon. For example, the familiarity of a child with words referring to fruits (e.g., “banana”, “apple”, “orange”) can facilitate the learning of a novel label referring to a fruit she is encountering for the first time. Thus, for example, the learning of the novel label "mango" might be facilitated by her previous knowledge associated with other fruits (e.g., "sweet", "small", "eaten as a snack or dessert"). Thus, the higher target recognition of novel phono-semantic related words than unrelated words in study three can be explained by the leveraging effect of the shared features between the novel words in the phono-semantic related condition. Also, the higher novel target recognition in the phono-semantic related condition than in the unrelated condition in study three can be accounted by the Distributed Cohort Model of word recognition (DCM, Gaskell & Marslen-Wilson, 1997). The DCM suggest that the words phonological and semantic aspects are processed simultaneously during speech processing, and both sources of information support the activation of the right word for recognition. Thus according to the DCM, higher target recognition is expected under situations where words overlap in form and meaning than unrelated words.

An implication of Study III to Distributed Cohort Model is that their predictions and assumptions can be extrapolated to the case of novel word recognition in young children since our results showed that phonological and semantic features of recently acquired words are encoded, assessed, and also used for novel word recognition. In addition, a general practical extension of Study III to models of word learning is that the recognition of recently acquired words by young children can be supported by the partial overlap of phonological or semantic aspects, but not by the complete overlap on these two dimensions or by the not overlap at all.

VI. F. Limitations and outlook

Next, some limitations on the studies of this dissertation will be mentioned.

Study I

In study one and two, the longer time between prime offset and target onset used may have impacted on the finding of semantic interference effects, and not semantic facilitator effects.

Study II

In Studies I and II, the variability in participants' age (and vocabulary) may had contributed to find phonological and phono-semantic interference effects. Another reason for not finding facilitator priming effects in the phono-semantic related condition in study two may have been driven by the type of the semantic link that was manipulated, namely taxonomical (e.g., "turtle"-"turkey", both belonging to the same taxonomical category "animals"). This may have been a problem, given that previous research with semantic additive priming has shown that only from the second year of life such a relationship facilitates word recognition (Arias-Trejo & Plunket, 2013; Willits et al., 2013).

Study III

Finally, in study three, the absence of trials where familiar objects were presented and one of them named may have reduced participants' attention to the task and, consequently, contributed to not finding evidence of word learning in the total looking time analyses. Also, for instance, the study of Fennel & Waxman (2010) included trials with familiar items, which may have clarified the task for infants.

Future direcctions

- The persistent evidence of interference effects found in the studies of this thesis indicates that children activate related candidates upon hearing the prime, but then their activation is not reduced when hearing the target, interfering with its recognition. Based on those results, it would be interesting to carry out longitudinal studies in which language processing skills are measured along with measures of Executive Functions, such as selective attention and inhibitory control. According to models of word learning and recognition (Cohort Model, Marslen-Wilson & Tyler, 1980; LEX model, Regier, 2005), those superior cognitive functions play a crucial role in recognition and learning. Because that selective attention is fundamental to discriminate between similar words in form and select the appropriate word for recognition; while inhibitory control might help reduce the activation of related yet not the target for recognition.
- Following up the finding of the effect of vocabulary size on interference effects in Study I, and of the connectivity of modelled networks of children vocabularies (Arias-Trejo, et al., 2022); we are currently preparing a publication where we compare the longitudinal vocabulary networks of the German and Spanish sample of participants with their word learning rate and priming performance.
- Further research could also aim to investigate how phonological and semantic priming effects are developed in bilingual children following a longitudinal approach.
- Future research interested into studying facilitator priming effects on word recognition in young children should investigate which experimental aspects leads to facilitation and which to interference. Thus, it would be relevant to test the effects of shorter versus longer intervening stimulus intervals between prime and the proportion of related versus unrelated trials presented to participants, as both factors have been associated with processing bias in adults (Hamburger & Slowiaczek, 1996).
- For the research on the effects of the simultaneous activation of phono-semantic links between words, it would be recommended to test participants older than 24 months of age or to test associative semantic links instead of semantic taxonomic links with younger children.
- Future research on novel word recognition may be benefited from the inclusion of trials with familiar objects (e.g., “dog” and “car”) to show children that the name of one of the objects will be named; thus, they will be prepared to look at the right referent upon hearing the novel labels. Also, it would be interesting to test the hypothesis of the LEX model (Regier, 2005) in the context of children learning similar formed labels and shared perceptual overlap between referents.

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Publications

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Congress presentations

Avila-Varela, D. S. & Sebastian-Galles, N. (2021, August). Study of labels phonological overlap across languages in bilingual toddlers. Poster session presented at the 6th Lancaster International Conference on Infant and Early Child Development, virtual event.

Avila-Varela, D. S. & Sebastian-Galles, N. (2020, July). Study of phonological overlap across languages in bilingual toddlers. Poster session presented at the virtual International Congress of Infant Studies, virtual event.

Avila-Varela, D. S., Arias-Trejo, N. & Mani, N. (2017, August). Longitudinal Study of Phonological and Semantical Priming Effects in German and Mexican Monolingual Infants. Poster session presented at Helsinki Summer School, Helsinki, Finland.

Avila-Varela, D. S., Arias-Trejo, N. & Mani, N. (2017, June). Longitudinal Study of Phonological and Semantical Priming Effects in German and Mexican Monolingual Infants. Poster session presented at the Workshop on Infant Language Development, Bilbao.

Avila-Varela, D. S., Arias-Trejo, N. & Mani, N. (2017, April). Longitudinal Study of Phonological and Semantical Priming Effects in German and Mexican Monolingual Infants. Poster session presented at the Biennial Meeting of the Society for Research in Child Development, Austin, Texas

Congress presentations (collaborations)

Siow, S., Gillen, N, Lepadatu, I., **Avila-Varela, D.,** Garcia-Castro, G., Sebastian-Galles, N. & Plunkett, K. (2021, August). A study of linguistic distance and infant vocabulary trajectories using bilingual CDIs of English and one additional language. Talk presented at the 6th Lancaster International Conference on Infant and Early Child Development, virtual event.

Garcia-Castro, G., **Avila-Varela, D. S.** & Sebastian-Galles, N. (2020, July). Does phonological overlap across translation equivalents predict earlier age of acquisition? Poster presented at the virtual International Congress of Infant Studies, virtual event.

Angulo-Chavira, A. Q., Chua-Rodriguez, F., **Avila-Varela, D. S.**, Mani, N. & Arias-Trejo, N., (2020, April). Longitudinal analysis of early semantic and phonological networks. Poster presented at the Society for Research in Child Development 2021 Virtual Biennial Meeting, virtual event.

General public presentations

Avila-Varela, D. S. (2021, November). Cross-language phonological overlap in bilingual toddlers. Presentation at the Multilingual Mind: Lecture Series on Multilingualism Across Disciplines, virtual Lecture Series, held online, Konstanz, Germany.

Avila-Varela, D. S. (2021, June). Studying babies' minds: From logical thinking to language acquisition. Talk presented at the Barcelona's Biennal Ciutat i Ciència, Barcelona, Spain.

Avila-Varela, D. S. (2021, February). Studying babies' minds: From phonemes discrimination to words acquisition. Talk presented at the civic centre Sagrada Familia, Barcelona, Spain.