Phonological Priming in Infancy

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Abstract

Adults recognise words faster given prior exposure to phonologically or semantically related words compared to unrelated words, suggesting that words are organised in the adult lexicon based on their phonological and semantic properties and that word recognition implicates not just the heard word, but also related words. The organisation of words in the infant lexicon, however, remains unexplored. The current experiments examine the phonological organisation of the infant lexicon using a picture priming technique, hitherto not used with infants: 18- and 24-month-old infants were faster at recognising words when preceded by phonologically related primes compared to unrelated primes. In addition, word recognition in 24-month-olds was impaired when the number of phonologically similar words known to infants was large, suggesting that, the 24-month-old mental lexicon has begun to be organised on the basis of the phonological properties of words.

Keywords: Phonological priming; cohort effects; infancy; lexical interference; phonological facilitation

Introduction

The current study investigates the cognitive processes involved in infant word recognition. We examine how words are represented in the infant mind, specifically focussing on whether the phonological properties of words are important for their organisation in the infant lexicon. The organisation of the adult lexicon has been studied by using priming techniques. For instance, adult word recognition studies report that hearing a word influences subsequent recognition of phonologically and semantically related words (Goldinger, Luce & Pisoni, 1989; 1992; Marslen-Wilson & Zwitserlood, 1989; Slowiaczek, Nusbaum & Pisoni, 1987; Slowiacek & Hamburger, 1992): word recognition is primed by prior exposure to phonologically and semantically related words. These findings have been taken to suggest that hearing a word leads to the activation of phonologically and semantically related words, and also that the phonological and semantic properties of words provide an organising principle for words in the adult lexicon. We follow a similar rationale to that used in adult studies of the mental lexicon by testing phonological priming in infancy to examine whether prior exposure to phonologically related primes influences subsequent infant word recognition, and use this to investigate the developmental trajectory of phonological neighbourhoods in the infant lexicon.

Studies investigating the mechanisms underlying phonological priming behaviour in adults offer two explanations for the patterns of results reported to date. These mechanisms can be summarised in terms of pre-lexical or phonological level facilitation effects, exemplified by speeded recognition of a word which is related to the prime word, and lexical level interference effects – slower recognition of words related to a prime word (Slowiaczek & Hamburger; 1992). For instance, adults recognise a target word like *dread* faster when the word is preceded by a phonologically related prime like *dream* compared to an unrelated prime like *scream* (Marslen-Wilson & Zwitserlood; 1989; Slowiaczek, Nusbaum & Pisoni, 1987; among others).This facilitation effect holds when the locus of phonological similarity is at the beginnings (e.g., *captain-capital*) or ends of the words (e.g. *hat*-*cat*). The finding of a facilitation effect does not necessarily imply that hearing a word leads to the partial activation of phonologically related words (Marslen-Wilson & Zwitserlood, 1989). The prime word may only activate its constituent sounds (e.g., *dread* activates /d/), making it easier for adults to achieve recognition of other words beginning with /d/ because the initial phoneme has already been activated. According to this explanation, the facilitation effect can be understood as a pre-lexical level effect, tapping into the phonological realms of the priming process.

Clearer evidence for a lexical level priming effect comes from studies investigating phono-semantic relationships between words (Marslen-Wilson & Zwitserlood, 1989). In these studies, the target word to be recognised (e.g., *dog*) is not phonologically related to the prime (e.g., *cup*), but is semantically related to a word that is (*dog* is semantically associated with *cat*, which in turn shares the initial consonant with *cup*). Since *dog* and *cup* do not share any sounds, facilitation of target word recognition must derive from activation of words phonologically related to *cup*, and subsequent priming of words semantically related to *cat*, i.e., *dog*. While these experiments report facilitation of target word recognition, this facilitation effect vanishes when there are more than two competitor words (phonologically related neighbours): the activation of many words that are phonologically related to the prime interferes with target word recognition.

The interference effect explains why adults are sometimes slower at recognising words given previous exposure to phonologically similar words compared to unrelated words (Goldinger, Luce, Pisoni & Marcario, 1992; Slowiaczek & Hamburger, 1992; among others). Phonological primes activate a *cohort* of words that are related to the target, creating a competitive environment, which slows down its recognition. The interference effect thus provides evidence for priming having a direct impact on the lexical level of processing.

Despite the extensive literature on phonological priming with adults, phonological priming in infancy has not been examined using either behavioural or electrophysiological measures. One might expect infants to show very different patterns of responding to adults. Infants do not know as many words as adults. Consequently, these words may have independent representations, such that activation or recognition of a word does not lead to activation of phonologically related words. On this account, we would not expect infants' recognition of words to be influenced by lexical level effects, only pre-lexical effects. In other words, we predict that only facilitation effects will occur in a lexicon with no phonological neighbourhoods.

On the other hand, infants might take advantage of the words they already know to help them learn new words. It might be easier to learn words that are phonologically or semantically related to previously learnt words. On this scenario, infants might be expected to show similar patterns of priming to adults, because it might now be easier to form links between words that are phonologically related to each other. Hence, this account would predict both phonological facilitation and lexical interference effects in infants. It should be noted, however, that other researchers (Swingley & Aslin, 2007) report that 18-month-olds find it harder to learn new words which sound similar to previously known words compared to words with no similar-sounding neighbours. One interpretation of Swingley & Aslin's results is that infants have difficulty building a mental lexicon consisting of densely populated phonological neighbourhoods. On this view, then, we would predict that that phonologically related words will not interfere with recognition of words at 18-months: 18-month-olds will show phonological facilitation but not lexical interference effects. Older infants, such as infants past the vocabulary spurt, might find it easier to build a mental lexicon around phonological neighbourhoods, and indeed, might need phonological neighbourhoods to organise the words in their advanced lexicon. This approach predicts that lexical interference should emerge later in lexical development.

It is important to note also that Swingley & Aslin tested infants' learning of words that rhymed with familiar words. Adults, typically, show lexical interference effects only with cohort members (words beginning with the same sounds, e.g., *cat*-*car*) but not with rhyming words (Emmorey, 1989; Praamstra, Meyer & Levelt, 1994, Radeau, Morais & Segui, 1995). In contrast to their performance with rhyming words then, infants may find it easier to learn words that begin with the same sound as other already known words. It may then be easier for infants to form links between words that belong to the same cohort. On this view, infants may show lexical interference effects when the prime and target word begin with the same sound.

One might also expect infants to be influenced by the size of the related cohort – larger cohorts have more words competing with the target word for recognition and may delay target recognition longer than smaller cohorts. In adults, the activation of phonologically related words interferes with target word recognition only when the cohort size is more than 2 words (Marslen-Wilson & Zwitserlood, 1989). Therefore, we predict that if infants show interference effects, there will be greater interference with words from large cohorts than words from small cohorts.

Method

Participants

The participants in this experiment were 27 infants at 18-months (M = 17.84 months; Range = 17.06 to 18.73 months) and 32 infants at 24-months (M = 23.96 months; Range = 23.18 to 24.28 months). 13 additional infants were tested but were excluded due to fussiness or parental interference (6 at 18-months; 7 at 24-months). Infants had no known hearing or visual problems, were recruited via the maternity ward at the local hospital, and came from homes where British English was the primary language in use. All parents were asked to complete the British Communicative Developmental Inventory (Hamilton, Plunkett & Schafer, 2000).

Procedure

During the experiment, all infants sat on their caregiver's lap approximately 80 cm away from a screen (88 × 24 cm). Two cameras mounted directly above the visual stimuli recorded infants' eye movements. Synchronised signals from the two cameras were then routed via a digital splitter to create a recording of two separate time-locked images of the infant.

Each infant was presented with 16 trials. Each trial began with the presentation of a centrally located image of a familiar object on-screen for 1.5s (the prime image). The prime image was presented in silence. At the offset of the prime image, the screen was blank for 200ms, followed by the presentation of two images of familiar objects side-by-side for 2.5s. 50ms after the onset of these two images, infants were presented with a label for the target image in citation form. The auditory signal was presented through a pair of centrally located loudspeakers situated above the screen.

In half the trials (primed trials), the heard label began with the same consonant as the unheard label for the prime image. For instance, in a primed trial, infants were presented with an image of a bed in silence for 1.5s, followed (after a 200ms blank screen) by the simultaneous presentation of a boot and a fork. 50ms after the boot and fork appeared on-screen, infants heard the word *boot*. In the other half of the trials (unrelated trials), the heard label was phonologically unrelated to the label for the prime image.

The speech stimuli were produced by a female speaker of British English in an enthusiastic, child-directed manner. We chose words that 50% of infants at a younger age were familiar with in order to maximise the likelihood that these words were known to the infants being tested. Visual stimuli were computer images created from photographs, with one image for each word. The prime image appeared in the centre of the screen, while the target and distracter images appeared side-by-side on the screen.

Note that the prime image was never labelled. Previous research has shown that infants can internally generate a label for a name-known image (Mani & Plunkett, 2007; under review). Allowing infants to generate the labels associated with the picture prime removes the constraint of having to label the prime image. This can be advantageous, since the rapid succession of presentation of prime and target labels can prove distracting for infants (Styles, Arias-Trejo & Plunkett, 2007).

All labels for the target and prime images, and the distracter and prime images were semantically and associatively unrelated (according to the Edinburgh Word Association Thesaurus and the Birkbeck Word Association Norms, Moss & Older, 1996). The distracter image was never labelled, and the label for the distracter image was phonologically unrelated to the target or prime label. Infants saw each image only once during the experiment. Across infants, target and distracter pairings were maintained. Target-distracter pairs appeared in the primed and unrelated condition with equal frequency across infants. Primes were similarly counterbalanced, so that the same prime image appeared in the primed and unrelated condition with equal frequency across infants. Targets appeared equally often to the left and to the right. Order of presentation of trials was randomised across infants.

Scoring

A digital-video scoring system was used to assess visual events on a frame-by-frame basis (every 40ms). This technique enabled tracking of every eye movement. A second skilled coder evaluated the data from 10% of the participants. Coders achieved a high level of agreement (r =.99).

Most previous research assumes that it takes around 367 ms for infants to initiate an eye movement in reponse to an auditory stimulus (Fernald, Swingley & Pinto, 2001; Swingley & Aslin, 2000). However, preliminary analysis of the data showed that infants had already made a switch to fixate on either the target or the distracter within 132ms. Faster switches to the images in the current study can be attributed to the fact that recognition is primed by prior exposure to a related image. Consequently, we analysed an extended time-window that considered all eye movements that took place 100ms after the onset of the target word to the end of the trial.

The coded video frames were used to determine the amount of time infants looked at the target (T) and distracter (D) images. Only those trials in which infants fixated both the target and the distracter image were included. We then calculated the proportion of time (T / (T + D)) infants spent looking at the target 100 ms after target word onset – a Proportion of Target Looking measure (PTL).

We also report the amount of time taken by infants to switch from the distracter image to the target image upon hearing the target label as an index of infants' preference for the target image (Fernald, Swingley & Pinto, 2001; Swingley & Aslin, 2000). Once again, only eye-movements 100 ms after the onset of the target word were considered. A rapid change in gaze after this point is taken as a measure of infants' detection of a mismatch between the picture currently fixated (i.e., the distracter image) and the target label.

Results

A repeated measures ANOVA with condition (primed or unrelated) as a within-subjects factor and age as a between-subjects factor using the proportional target looking data found a significant main effect of age ($F (1, 57) = 18.232$; $p < .001$), no effect of condition and a significant interaction between priming and age ($F (1, 57) = 14.629$; $p < .001$). Consequently, we analysed the two age-groups separately.

Phonological Priming

18-months

Latency measure: We analysed only those trials where infants were already looking at the distracter image at the disambiguation point (100ms after target word onset). We then compared the time taken by infants to switch from the distracter to the target image in primed and unrelated trials. This included 29% of all trials (130 out of 436 trials). Infants took less time to switch from the distracter to the target image in primed trials (M = 941ms) compared to unrelated trials (M = 1070 ms; $t (128) = 2.136$, $p = .03$).

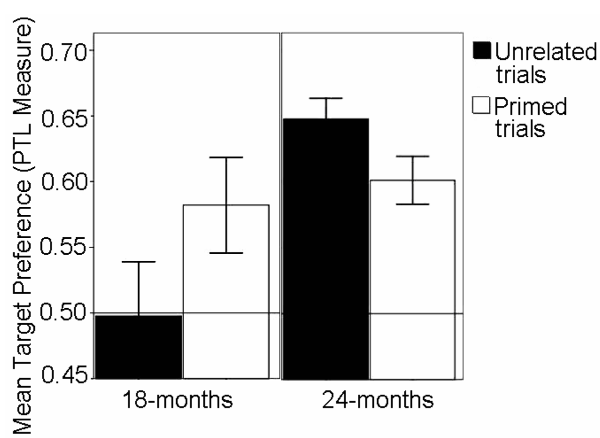

Figure 1: Proportion of target looking in primed and unrelated trials at 18- and 24-months (+/- 1 SE)

PTL measure: Infants looked at the target above chance (50%) in primed trials (M = 58%, t (26) = 4.63, p < .001) but not in unrelated trials (M = 49%, t (26) = -.11, p > .5). In addition, infants looked significantly longer at the target in primed trials compared to unrelated trials (t (26) = 3.056, p = .005).

24-months

Latency measure: Using the same trial exclusion criteria as was used with the 18-month-olds, latency analysis considered 35% of all trials (189 out of 539 trials). Infants were faster to switch from the distracter to the target image in primed trials (M = 778ms) compared to unrelated trials (M = 858 ms; t (187) = 2.075, p = .03).

PTL measure: Infants looked at the target above chance in both primed (M = 59%, t (31) = 5.34, p < .001) and unrelated trials (M = 64%, t (31) = 9.24, p < .001). In contrast to the 18-month-olds, 24-month-olds looked longer at the target in unrelated trials compared to primed trials (t (31) = 2.181, p = .03).

Cohort effects

We also analysed whether target recognition was influenced by the number of words known to infants that began with the same consonant as the label for the prime images. Prime words presented to infants began with one of five consonants /b/ (7), /d/ (2), /p/ (2), /t/ (1), and /k/ (4). Using the vocabulary data collected from parents, we determined that infants knew 38 words beginning with /b/ (38 at 18-m, 39 at 24-m), 19 /k/ words (19 at 18-m, 19 at 24-m), 16 /d/ words (14 at 18-m, 18 at 24-m), 18 /p/ words (16 at 18-m, 21 at 24-m) and 20 /t/ words (19 at 18-m, 21 at 24-m). Consequently, we separated the trials into large cohort trials (i.e., only those trials where the label for the prime image began with /b/, n = 7) and small cohort trials (i.e., all other trials, n = 9).

18-months: A repeated measures ANOVA found a significant main effect of priming (F (1, 25) = 7.35; p = .012), but no effect of cohort size (F (1, 25) = .10; p = .75) or interaction between cohort size and priming (F (1, 25) = .885; p = .35), indicating that there was no influence of cohort size on priming at 18-months of age. There was no difference in infants' latencies to switch to the target based on whether the target label was from a large or small cohort in primed (t (57) = .38; p > .5) or unrelated trials (t (69) = -1.5, p = .12).

24-months (see Figure 2): A repeated measures ANOVA found no main effect of priming or cohort size (Fs < 1) but a significant interaction between cohort size and priming (F (1, 31) = 17.96; p < .001). Infants looked longer at the target in unrelated trials compared to primed trials (t (31) = 2.86; p = .007) when the label for the prime image was from a large cohort. In contrast, infants looked longer at the target in primed trials compared to unrelated trials (t (31) = -2.15; p = .039) when the label for the prime image was from a small cohort. Infants looked at the target above chance in unrelated trials, irrespective of cohort size (large cohort: t (31) = 3.24, p = .003; small cohort: t (31) = 5.87; p < .001). Infants looked at the target above chance in primed trials when the label for the prime image was from a small cohort (t (31) = 5.62; p < .001), but not when the label was from a large cohort (t (31) = 1.53; p = .12). There was no difference in infants' latencies to switch to the target between primed and unrelated trials based on whether the target label was from a small (t (90) = .96; p = .3) or large cohort (t (95) = .62, p = .53).

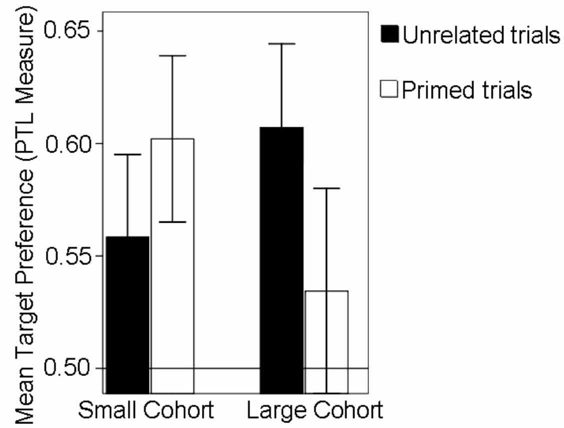

Figure 2: Cohort effects at 24-months (+/- 1 SE)

General Discussion and Conclusion

18- and 24-month-olds displayed robust phonological priming effects as calculated by PTL and latency measures, albeit in very different ways. Both age-groups displayed speeded response latencies to move to the target image in primed trials compared to unrelated trials. 18-month-olds showed phonological facilitation of target recognition by looking longer at the target in primed trials compared to unrelated trials. 24-month-olds, in contrast, showed lexical interference with target recognition by looking longer at the target in unrelated trials compared to primed trials. In addition, target recognition at 24-months was influenced by cohort size – 24-month-olds showed lexical interference effects when the target label was from a large cohort and phonological facilitation effects when the target label was from a small cohort. The cohort effects provide clear evidence that word recognition involves the activation of phonologically related words at 24-months of age.

Note that the prime image was never labelled and that the prime was semantically and associatively unrelated to the target and distracter. The difference in infants' responding in primed and unrelated trials can only be explained by assuming that infants internally generated a label for the prime image, which acts as the prime for subsequent responding. The current experiments support the conclusion of previous research (Mani & Plunkett, 2007; under review) that infants generate a phonological representation of visually presented images. In what follows, we discuss the implications of the results with the PTL and latency measures in order to examine the mechanisms behind the reported priming effects.

Latency analysis: At 18- and 24-months of age, infants switched faster from the distracter to the target image in primed trials compared to unrelated trials. The label for the target image shares the onset consonant with the label for the prime image in primed trials. In primed trials, the onset consonant of the heard label has already been activated by infants' generation of the phonological representation of the label for the prime image. Consequently, the mismatch between the label for the distracter image and the heard label is detected faster in primed trials compared to unrelated trials, hence motivating faster switches away from the distracter image in primed trials compared to unrelated trials. The latency analysis provides evidence of phonological level facilitation of target recognition. Note, however, that these results do not necessarily imply that activation of the prime label leads to lexical activation of phonologically related words at 18- or 24-months.

PTL analysis: 18-month-olds spent longer looking at the target image in primed trials compared to unrelated trials. These results suggest that if the target label is phonologically, semantically, and associatively unrelated to the label for the prime image, then exposure to a prime image interferes with identification of the referent of the target label. It is important to note that the image itself is not the cause of reduced target recognition in unrelated trials; rather it is the sounds of the label for the prime image. The phonological mismatch between the heard label and the prime label leads to reduced target recognition in unrelated trials. In primed trials, however, the elicited label shares the onset consonant of the heard target label and does not interfere with target recognition. A similar pattern of results is found in semantic priming studies with infants (Styles, Arias-Trejo & Plunkett, 2007) – infants show impaired target recognition if the prime label is semantically unrelated to the target label. The current study replicates this absence of target recognition following phonologically and semantically unrelated primes and suggests that this may be a robust index of interference caused by an unrelated prime on target recognition.

At 24-months of age, while infants showed target recognition in primed and unrelated trials, infants spent longer looking at the target following unrelated trials compared to primed trials. We suggest that at 24-months, prior exposure to the prime image activates not just the label for the prime image, but also words phonologically related to this label in the infants' lexicon. The competitive environment introduced by the activation of these phonologically related words interferes with target recognition, causing infants to spend less time looking at the target in primed trials compared to unrelated trials.

Cohort analysis: At 18-months of age, there was no influence of cohort size on target recognition using either the latency or the PTL measure. Note that cohort interference effects are interpreted in the adult word recognition literature as evidence for lexical level activation (Marslen-Wilson & Zwitserlood, 1989). The absence of any cohort effects provides support for the argument that activation of the label for the prime image does not lead to activation of phonologically related words at 18-months.

There was a robust effect of cohort size on the proportion of time infants spent looking at the target at 24-months. When the prime label was from a large cohort (i.e., began with /b/), infants showed impaired target recognition in primed trials compared to unrelated trials. This provides strong evidence that activation of the prime label leads to activation of related words. Activation of large cohorts of related words at 24-months creates a competitive environment which interferes with target recognition. These are precisely the results obtained with adults in phono-semantic priming tasks (Marslen-Wilson & Zwitserlood, 1989).

There was no evidence of cohort interference effects when the prime label was from a small cohort (i.e., began with /d/, /k/, /p/ or /t/). Furthermore, infants looked longer at the target in primed trials compared to unrelated trials. A similar pattern of results was found at 18-months, irrespective of cohort size. Overlap of the onset consonant of the prime and target label aids recognition of the target label in primed trials. The absence of similar overlap in unrelated trials impairs target recognition. These results do not provide evidence of lexical level activation, rather of phonological facilitation of target recognition of words from small cohorts. When smaller cohorts are involved, activated cohort members may not be sufficient to interfere with target recognition. Alternatively, these similar-sounding words may not be activated due to the global activation levels of the small cohort being lower than the global activation level of a larger cohort, or the neighbours in the smaller cohort having a higher frequency than the target word.

Note also that infants were presented with 7 /b/ target words, compared to a smaller number of words beginning with other sounds. Could the cohort effect have been caused by this imbalance, resulting from the cohort of /b/ words being naturally more activated than other words? We ensured that /b/ words for both the prime and the target were spread equally across primed and unrelated trials. Consequently, any additional difference between primed and unrelated trials could have only been caused by the presentation of a prime image whose label began with the same consonant as the label for the target image.

We have focussed on the label for the prime image in describing the activated cohorts. However, it is possible that hearing the target label may also have activated a cohort, which may have influenced recognition. The finding that the prime's cohort produced a significant interaction between priming and cohort size suggests that the prime's cohort is the central motivator of the lexical level effects observed in the current study. Indeed, similar analyses conducted using the target's cohort found no significant interaction between cohort size and priming at 18- ($F = .61$) or 24-months of age ($F = .76$).

The differences between the results with the on-line and off-line measures and the cohort analysis of the two age-groups provide us with some insights into the mechanisms underlying phonological priming behaviour in infancy. The absence of cohort effects using the latency measure and the contrasting robust cohort effect using the PTL measure suggests that these two measures are indexing different stages in the process of word recognition. The latency measure appears to be tapping into the early phonological stages of the priming process, indexing pre-lexical facilitation effects. The proportional measure, on the other hand, includes changes in eye-fixations throughout the trial and offers an index of later lexical level phenomena, such as cohort interference effects.

Note that it could be argued that the PTL results at 24-months could be explained by suggesting that recognition of the target is achieved faster in primed trials, leading to infants switching away from the recognised object to the distracter, and consequently shorter looking times in primed trials. However, in the Inter-modal preferential looking literature, longer looking times have invariably been interpreted as an index of the strength of the association between the fixated object and the heard label. To argue that shorter looking times also indicate better recognition of the target would contradict most of the preferential looking literature to date. In addition, large cohorts have been repeatedly found to interfere with target recognition in the adult literature. To suggest that the shorter looking times in large cohort trials now indicates facilitation of target recognition would, again, contradict the substantial priming literature to date.

The experiments presented here provide clear evidence of the development of phonological neighbourhoods in the infant lexicon by 24-months of age. While there is also evidence of phonological priming at 18-months, we have argued that this does not offer a conclusive demonstration of phonological neighbourhood activation. 18-month-olds displayed only phonological level facilitation effects, while 24-month-olds displayed phonological facilitation and lexical interference effects. As predicted, lexical interference effects at 24-months were modulated by cohort size – infants showed lexical interference effects with words from large cohorts, and phonological facilitation effects with words from small cohorts. Taken together with Swingley & Aslin's (2007) results that 18-month-olds have difficulty learning new words that are phonologically similar to known words, the evidence from the current study suggests that words are unrelated in the mental lexicon at 18-months of age. By 24-months of age, infants' responding in word recognition tasks approximates to adult-like performance and words begin to cluster together in the infant lexicon based on their phonological properties, such that word recognition involves the activation of phonologically related words.

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