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PAPER

Word-form familiarity bootstraps infant speech segmentation

Nicole Altvater-Mackensen[1,2] and Nivedita Mani[2]

1. Research Group Early Social Development, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany
2. Research Group Language Acquisition, Georg-August-Universität, Göttingen, Germany

Abstract

At about 7 months of age, infants listen longer to sentences containing familiar words – but not deviant pronunciations of familiar words (Jusczyk & Aslin, 1995). This finding suggests that infants are able to segment familiar words from fluent speech and that they store words in sufficient phonological detail to recognize deviations from a familiar word. This finding does not examine whether it is, nevertheless, easier for infants to segment words from sentences when these words sound similar to familiar words. Across three experiments, the present study investigates whether familiarity with a word helps infants segment similar-sounding words from fluent speech and if they are able to discriminate these similar-sounding words from other words later on. Results suggest that word-form familiarity may be a powerful tool bootstrapping further lexical acquisition.

Research highlights

- Being familiar with a word helps infants segment similar-sounding words from fluent speech: German 7-month-olds segment novel words more easily from continuous speech when they have been familiarized with a word that sounds similar compared to a phonologically unrelated word.
- This is the first evidence of a potential phonological familiarity effect in infant lexical acquisition where learning one word facilitates the *segmentation* of other similar sounding words in speech.
- Word-form familiarity may be a powerful tool bootstrapping further lexical acquisition.

Introduction

Nearly two decades ago Jusczyk and Aslin (1995) showed that by 7.5 months of age, infants are able to segment words from fluent speech. Subsequent studies stressed the importance of different sources of information such as the transitional probability of syllables (Saffran, Aslin & Newport, 1996), phonotactic knowledge (Jusczyk, Hohne & Baumann, 1999), word stress (Jusczyk, Houston & Newsome, 1999) or position within the sentence (Seidl & Johnson, 2006) in driving infants' detection of word boundaries in fluent speech. Furthermore, infants appear to remember words they segment from the speech stream well before they learn their meanings (Jusczyk & Hohne, 1997). This corroborated the idea of a *proto-lexicon* representing the segmented sound clusters. It is argued that this proto-lexicon aids infants' segmentation of new words (Peters, 1983) and facilitates later word learning (Graf-Estes, Evans, Alibali & Saffran, 2007).

It seems reasonable to expect that known words facilitate segmentation. Hearing a few familiar words in an unfamiliar foreign language immediately draws attention to these familiar words and allows non-native speakers to place word boundaries in an otherwise incomprehensible speech stream. Adults appear to use a similar strategy when isolating words in artificial language learning experiments (Cunillera, Camara, Laine & Rodriguez-Fornells, 2010). Similarly, 6-month-olds segment novel words more easily from utterances when they are preceded by the infant's name or a highly familiar

Address for correspondence: Nicole Altvater-Mackensen, Max-Planck-Institut für Kognitions- und Neurowissenschaften, Stephanstrasse 1a, D-04103 Leipzig, Germany; e-mail: altvater@cbs.mpg.de

word like *mommy* (Bortfeld, Morgan, Golinkoff & Rathbun, 2005), and 8-month-olds isolate words more successfully when they are preceded by frequent functors (Shi & Lepage, 2008). These studies suggest that known words can facilitate segmentation of the speech stream by highlighting the ends of familiar words and, consequently, the beginnings of upcoming words. The strategy to use familiar words as an anchor when segmenting utterances might be employed from early on given that infants recognize their own name around 4.5 months of age (Mandel, Jusczyck & Pisoni, 1995) and other common words such as body parts at 6 to 9 months of age (Tincoff & Jusczyk, 1999, 2012; Bergelson & Swingley, 2012). Furthermore, familiarity with a word can help infants to cope with surface variation. While they tend to fail to equate instances of a word uttered by different talkers (Houston & Jusczyk, 2000; but see Van Heugten & Johnson, 2012, for findings that 7.5-month-olds generalize across speakers) or with different vocal affect (Singh, Morgan & White, 2004), they succeed in doing so with highly familiar words like *mommy* or *daddy* (Singh, Nestor & Bortfeld, 2008).

Familiar words might, however, not only be useful as anchors to segment following words from the speech stream or to equate word tokens with different surface characteristics. It might also be easier to isolate a novel word from an utterance when it sounds similar to a known word. That is, infants who know the word *doll* might find it easier to segment a similar-sounding novel word like *dog* from the sentence '*The girl played with the dog in the backyard*' relative to infants who are unfamiliar with the word *doll*. Findings from non-word repetition and word learning studies in toddlers and preschoolers support this view. Children are faster and more accurate in repeating common-sounding novel words (i.e. words that sound similar to other familiar words like *wat*) relative to uncommon words (e.g. *fawk*) (Coady & Aslin, 2004; Zamuner, Gerken & Hammond, 2004; Newman, Samuelson & Gupta, 2008). Similarly, they learn novel labels with high phonotactic probability faster than other words (Storkel, 2001; Storkel & Hoover, 2011). Storkel argues that these findings indicate that existing phonological representations can support lexical acquisition: new words that consist of common sound sequences may be relatively easy to process because of their phonological similarity to existing words. We speculate that a similar effect might be observed in younger infants' word segmentation.

Indeed, recent work by Lew-Williams and Saffran (2012) suggests that familiarity with the syllabic structure of a word influences infants' segmentation behavior. Using a three-phase design, Lew-Williams and Saffran (2012) asked if expectations about word length will influence infants' use of transitional probabilities to segment words from fluent speech. In an initial familiarization phase they exposed infants to lists of either disyllabic or trisyllabic words. A second segmentation phase then presented infants with a speech stream composed of (novel) words that again were either uniformly disyllabic or trisyllabic. When later tested on their recognition of the words presented in the speech stream, Lew-Williams and Saffran (2012) found that consistency of word length across familiarization and segmentation phase influenced infants' segmentation behavior: Infants segmented the speech stream successfully when word length was consistent across the familiarization and segmentation phase (i.e. both phases presented only disyllabic or only trisyllabic words), but they did not segment the speech stream when word length was inconsistent across phases. Thus young infants appear to be able to use a familiar syllabic structure (CVCV or CVCVCV) to better segment words from fluent speech.

Across three experiments, here, we examine whether these results are limited to syllabic structure or whether infants can also use their familiarity with the segmental content of words to better segment similar-sounding words from a fluent speech stream. That is, we examined whether infants are better able to segment novel words from fluent speech when these novel words differ minimally from words they are familiar with (compared to unfamiliar words that are not phonologically related to a familiar word).

Experiment 1: Onset overlap

Experiment 1 tested infants' segmentation of words that did or did not overlap phonologically at word onset with familiar words. The experiment was structured into three phases (as in Lew-Williams & Saffran, 2012). Phase 1 – the familiarization phase – familiarized the infants with two words. Given that infants only know a limited number of words and given that these words probably differ across infants, we decided to not rely on previous lexical knowledge. Instead we used an initial familiarization phase (similar to previous segmentation studies) to ensure that all infants were familiar with the words that we considered familiar. In addition, this allowed us to control for possible stimulus confounds by counterbalancing which words we familiarized the infants to. Phase 2 – the segmentation phase – presented the infants with sentences containing two types of unfamiliar words: words that sounded similar to the familiarized words and words that were phonologically unrelated to the familiarized words. Phase 3 – the test phase – tested

Table 1 *Schematic of experimental procedure and results. The schematic describes one condition of each experiment to illustrate the procedure. Which word pair was presented in Phase 1 was counterbalanced across infants (i.e. the same word pair served as familiar, similar-sounding and phonologically unrelated in different infants)*

	Experiment 1	Experiment 2	Experiment 3
Phase 1: Words in isolation	*Löffel* / *Mütze*	*Löffel* / *Mütze*	*Löffel* / *Mütze*
Phase 2: Words in sentence context	*Löckel* / *Müpfe* *Sotte* / *Tacke*	*Nöffel* / *Pütze* *Konne* / *Fasse*	*Löffel* / *Mütze* *Sonne* / *Tasse*
Phase 3: Words in isolation	*Löckel* / *Müpfe* *Sotte* / *Tacke*	*Nöffel* / *Pütze* *Konne* / *Fasse*	*Löckel* / *Müpfe* *Sotte* / *Tacke*
Preference in Phase 3	*Löckel* / *Müpfe*	*Nöffel* / *Pütze*	no preference

recognition of the similar-sounding words compared to the phonologically unrelated words from Phase 2 in isolation. For instance, an infant was familiarized with the two words *Löffel* 'spoon' and *Mütze* 'hat' in Phase 1. She then heard two types of words in sentence context in Phase 2: the two similar-sounding (pseudo-)words *Löckel* and *Müpfe*, and the two phonologically unrelated (pseudo-)words *Sotte* and *Tacke* (created from the words *Sonne* 'sun' and *Tasse* 'cup'). In Phase 3 the similar-sounding words (i.e. *Löckel* and *Müpfe*) and the phonologically unrelated words (i.e. *Sotte* and *Tacke*) were presented in isolation. See Table 1 for a schematic of the experimental procedure and the results.

Phases 2 and 3 are similar to the original Jusczyk and Aslin (1995) design in that the infants first hear sentences containing critical target words and are then tested on recognition of these words later on. However, all words presented during test (Phase 3) were presented equally often in sentence context (Phase 2). If phonological similarity to a word presented in Phase 1 does not lead to a segmentation advantage in Phase 2, there should be no preference for one type of word over the other in test (Phase 3) because infants have had equal exposure to these words in sentences in Phase 2.[1] If there is, however, a segmentation advantage for similar-sounding words (i.e. words that sound similar to the words presented in Phase 1), we expect a difference in preference between similar-sounding and phonologically unrelated words in test (Phase 3).

Method

Participants

Twenty German monolingual 7-month-olds (nine boys) participated in the experiment. Their ages ranged from 6;06 (months; days) to 7;25, mean age 6;29. Four additional infants were tested but were excluded because of unwillingness to participate/failure to provide data for all three phases of the experiment (three) or looking times more than two standard deviations above the mean (one). Infants came from a sample of families who responded to an invitation letter sent to all families with infants living in the area. Infants were rewarded with a T-shirt.

Stimuli

Visual stimuli consisted of a digital black-and-white checkerboard pattern on which random color squares appeared. Audio stimuli consisted of six-sentence passages containing a critical target word and target words in isolation. Target words included *Löffel* 'spoon', *Löckel*; *Mütze* 'hat', *Müpfe*; *Sonne* 'sun', *Sotte*; and *Tasse* 'cup', *Tacke*. Target words appeared at different positions within the sentences and were preceded and followed by various words as sentences were not repeated across passages.[2] The four different passages and the corresponding target words are listed in Table 2.

[1] Note that our terminology differs from previous segmentation studies due to the differences in design. Segmentation studies typically present words in passages during familiarization and then test preference for these words, typically termed familiar, above words that have not previously been presented, typically termed unfamiliar. Following this convention, we adopted the term familiar to label those words that the infants were familiarized with in isolation in Phase 1 (i.e. it does not refer to previous familiarity with the words). To avoid confusion, we do not use the term unfamiliar. This is because following the conventional terminology both types of words used in Phases 2 and 3 – similar-sounding and phonologically unrelated words – are unfamiliar in Phase 2 (as neither type has been presented in Phase 1), but familiar in Phase 3 (as they have both been presented in Phase 2).

[2] As one reviewer pointed out, previous research has shown that infants are better able to segment words from the initial or final edge of sentences than words in sentence-medial position (Seidl & Johnson, 2006), and that they can use transitional probabilities between syllables to detect word boundaries (Saffran *et al*., 1996). We used variegated sentence contexts to mimic natural speech (similar to the stimulus set used in Jusczyk & Aslin, 1995) and to prevent drawing infants' attention specifically to the critical words. Note, however, that we counterbalanced which words (and thereby which passages) served as familiar, similar-sounding or phonologically unrelated across infants. A word and passage pair that represented the similar-sounding condition in one infant served as phonologically unrelated condition in another child. Therefore, differences in the individual passages and words are unlikely to confound results. Furthermore, a repeated measures ANOVA confirmed that there was no main effect of item and no interaction of item by phase ($p > .1$ for all three experiments).

Table 2 *Stimulus set*

Passage 1: *Löffel* '*spoon*' /*Löckel*
Hast Du meinen schönen X gesehen? (Did you see my nice X?)
Er hat sein Essen mit einem blauen X gegessen.
(He ate his food with a blue X.)
Der X fiel ihm mit einem Klirren aus der Hand.
(The X fell out of his hand with a clank.)
Mein roter X ist in der Schublade. (My red X is in the drawer.)
Der Junge hat den X in seine Tasche getan.
(The boy put the X in his pocket.)
Der Elf hat unter dem Tisch nach seinem X gesucht.
(The elf looked for his X under the table.)
Passage 2: *Mütze* 'hat' /*Müpfe*
Ich möchte meine gelbe X tragen. (I want to wear my yellow X.)
Meine X ist nicht auf meinem Stuhl. (My X is not on my chair.)
Der Bär hat meine neue X gegessen. (The bear has eaten my new X).
Die grosse rote X ist im Schrank. (The big red X is in the closet.)
Der Mann setzte seine X auf und ging.
(The man put on his X and went away.)
Kannst Du meine X in Deinem Zimmer finden?
(Can you find my X in your room?)
Passage 3: *Sonne* 'sun' /*Sotte*
Die X stand hoch am Himmel. (The X was high in the sky.)
Alles, was man sehen konnte, war die grosse helle X.
(All you could see, was the big bright X.)
Er malte ein schönes Bild von der gelben X.
(He drew a nice picture of the yellow X.)
Die X schien den ganzen Tag. (The X was shining all day.)
Er konnte die X durch sein Fenster sehen.
(He could see the X through his window.)
Du bist glücklich, wenn die X scheint.
(You are happy when the X is shining.)
Passage 4: *Tasse* 'cup' /*Tacke*
Die X war hell und glänzte. (The X was bright and shiny.)
Der Clown trank aus der roten X. (The clown drank from his red X.)
Der Andere hat die grosse X genommen.
(The other one has taken the big X.)
Seine X war mit Milch gefüllt. (His X was filled with milk.)
Das Mädchen hat ihre X zurück auf den Tisch gestellt.
(The girl has put her X back on the table.)
Etwas Milch ist aus Deiner X auf den Teppich getropft.
(A bit of milk dripped from your X on the carpet.)

Sentences and words were spoken by a female native speaker of German in moderate infant-directed speech (mean target duration = 723 ms (isolated words) / 376 ms (sentence context); mean target amplitude = 62 db; mean target pitch = 187 Hz). Audio stimuli were digitally recorded in a quiet room with a sampling rate of 44.100 Hz and volume matched after recording using audio editing software.

Procedure

Infants were seated on their parent's lap in a quiet experimental room, facing a 92 cm wide and 50 cm high TV screen at a distance of 100 cm from the screen. Parents wore headphones playing music intermixed with speech during the experiment and were instructed to interact as little as possible with their child. Two cameras mounted above the screen recorded infants' eye-movements during the experiment. Synchronized signals from the cameras were routed via a digital splitter to record two separate time-locked images of the infant. Auditory stimuli were presented via loudspeakers that were located above the screen. Stimuli were presented using the Look software (Meints & Woodford, 2008). Each trial presented the checkerboard pattern on the screen paired with an auditory stimulus. A trained experimenter controlled the experiment from an adjacent room. Based on the video image, she started a trial when the infant was looking to the screen and continued to indicate throughout the trial whether the infant was looking to the screen or away by pressing the corresponding button on a keyboard. The experimenter was blind to which auditory stimulus was presented. In between trials the screen remained blank or a flashing light was displayed paired with the sound of a ringing bell to reorient infants towards the screen.

Phase 1 familiarized infants with two words, e.g. *Löffel* and *Mütze*. Each trial presented five tokens of one word with each token being repeated three times, separated by 1 second of silence, leading to 15 repetitions of the word per trial and a trial length of approximately 25 seconds. Words alternated between trials. Each trial lasted until completion or until the infant looked away for more than 2 seconds. Phase 1 ended after 12 trials or after the child had accumulated 100 seconds of looking time, equaling roughly 30 repetitions of each word. Across infants, we counterbalanced which words infants were familiarized with in Phase 1.[3]

Phase 2 presented infants with four different passages. Two passages contained words that sounded similar to the familiarized words from Phase 1, e.g. *Löckel* and *Müpfe*, henceforth similar-sounding words. Two passages contained words that were phonologically unrelated to the familiarized words, e.g. *Sotte* and *Tacke*, henceforth phonologically unrelated words. Similar-sounding words were created by changing the medial consonant of the previously familiarized words (in Phase 1). Each trial presented one passage, consisting of six sentences with 1 second of silence between sentences, adding up to a trial length of approximately 20 seconds. Each passage was presented three times so that six trials presented sentences with similar-sounding words and six trials

[3] Counterbalancing included all word pairs. Thus, we counterbalanced which words served as familiar, similar-sounding and phonologically unrelated across children. Consequently, infants could either hear the real word pairs *Löffel–Mütze* or *Tasse–Sonne* in Phase 1 or the corresponding similar-sounding pseudo-word pairs *Löckel–Müpfe* or *Tacke–Sotte*. Note that for simplicity's sake we adhere to the term word to refer to the critical target items regardless of whether they are existing German words or pseudo-words.

presented sentences with phonologically unrelated words. Trial order was randomized. Trials lasted until completion or until the infant looked away for more than two consecutive seconds.

Phase 3 presented the similar-sounding words, e.g. *Löckel* and *Müpfe*, and the phonologically unrelated words, e.g. *Sotte* and *Tacke*, from Phase 2 in isolation. Each word was presented in three trials, making a total of six trials presenting a similar-sounding word and six trials presenting a phonologically unrelated word. Each trial presented five tokens of one word with each token being repeated three times, separated by 1 second of silence, leading to 15 repetitions of the word per trial and a trial length of approximately 25 seconds. Each trial lasted until completion or until the infant looked away for more than 2 consecutive seconds. Trial order was randomized.

Data analysis

The looking behavior of the infants was reassessed offline using a digital video scoring system. A trained coder indicated for each 40 ms frame of the video whether the child was looking at the screen or away. The coder was blind to experiment phase and trial type. The coding output was aligned with information about the phase of the experiment and the auditory stimulus presented. For each infant we calculated the summed looking time during familiarization (Phase 1), the mean looking times in trials presenting sentences with similar-sounding and phonologically unrelated words (Phase 2), and the mean looking times in trials presenting similar-sounding and phonologically unrelated words in isolation (Phase 3).

Results and discussion

Looking time to familiarization in Phase 1 was 103 seconds (*SE* 4.0) (6.9 trials, *SE* 0.5), ranging from 61 seconds to 123 seconds.[4] In Phase 2, mean looking times were 8.8 seconds (*SE* 1.0) for trials presenting sentences with similar-sounding words and 8.5 seconds (*SE* 0.8) for trials presenting sentences with phonologically unrelated words. Paired *t*-tests showed no significant difference between sentence type ($p > .6$). In Phase 3, mean looking times were 6.4 seconds (*SE* 0.8) for trials presenting similar-sounding words and 5.4 seconds (*SE* 0.7) for trials presenting phonologically unrelated words. Paired *t*-tests confirmed that looking times for similar-sounding words were significantly higher than looking times for phonologically unrelated words ($t(19) = 2.422$, $p = .03$), indicating that infants had a preference for similar-sounding words over phonologically unrelated words.

The familiarity effect observed in Phase 3 suggests that infants segmented the similar-sounding words more easily from sentence context than the phonologically unrelated words in Phase 2, leading to a preference for similar-sounding over phonologically unrelated words: Familiarity with the word *Löffel* bootstraps infants' segmentation of a similar-sounding word *Löckel* from a fluent speech stream such that infants are able to better recognize this word when presented later in isolation. This provides the first evidence that familiarity with a word might help infants to segment similar-sounding words from fluent speech. It goes beyond the findings that phonotactic knowledge aids segmentation (Jusczyk *et al.*, 1999), that known words serve as a cue for segmentation of subsequent words (Bortfeld *et al.*, 2005) and that familiar syllabic structures might influence speech segmentation (Lew-Williams & Saffran, 2012). Furthermore, it extends the finding that previous familiarity with a word helps in abstracting away from surface variation (Singh *et al.*, 2008) by showing that familiarity helps not only recognizing the familiar word but also novel words that sound similar. Given that infants remember word-forms from early on (Jusczyk & Hohne, 1997), segmenting speech based on phonological similarity to already familiar words might be a powerful mechanism to aid early language learning. We will come back to this point in more detail in the general discussion.

The lack of preference for sentences with similar-sounding words compared to sentences with phonologically unrelated words in Phase 2 is in line with the original finding of Jusczyk and Aslin (1995): infants remember familiar words with sufficient phonological detail to not consider, for example, *Löckel* as a realization of *Löffel* in sentence context. Importantly, despite ease of segmentation not influencing listening times in Phase 2, infants appear to be able to better segment words from a fluent speech stream and/or better recognize these words later in isolation when the words sound similar to familiar words.

Young infants, however, seem to be more sensitive to word-onsets than to word-offsets (Vihman, Nakai,

[4] Note that absolute familiarization time might be lower than the familiarization criterion of 100 ms when the child did not reach the criterion within 12 trials. Absolute familiarization time might also be higher than the pre-set criterion as the last trial, once it had started, continued until completion if the child did not look away for more than 2 consecutive seconds, regardless of whether or not the 100 seconds had already been reached. However, the pattern of results was similar for infants below and above the median split of familiarization time, suggesting that the results are not driven by familiarization length *per se*. This holds for all three experiments.

DePaolis & Halle, 2004; Zamuner, 2006; Altvater-Mackensen & Fikkert, 2010). Furthermore, given onset overlap, infants might be garden-pathed into thinking that they were hearing the familiar word embedded in sentences (in Phase 2), pay more attention to this word, and realize only later on that they are being presented with a different word. Such garden-pathing may be obstructed in the case of words that overlap at offset but sound different at onset (e.g. *Löffel–Nöffel*). We examined, therefore, whether the current result is bound to onset overlap between familiar and similar-sounding word or whether it extends to phonological overlap more generally.

Experiment 2: Offset overlap

Experiment 2 employed the same design as Experiment 1, with the difference that similar-sounding words differed from familiar words in the initial rather than in the medial consonant. If the results of Experiment 1 are due to the onset overlap between similar-sounding and familiar words, we expect no preference for similar-sounding over phonologically unrelated words in test (Phase 3). If, however, the results of Experiment 1 are indicative of a more general influence of phonological similarity, we expect a similar preference for similar-sounding words over phonologically unrelated words in Phase 3.

Method

Participants

Twenty German monolingual 7-month-olds (11 boys) participated in the experiment. Their ages ranged from 6;03 to 7;27, mean age 7;0. An independent *t*-test confirmed that their ages were not different from those of the infants participating in Experiment 1 ($p > .6$). Two additional infants were tested but were excluded because of unwillingness to participate/failure to provide data for all three phases of the experiment. Infants came from the same sample of families as infants from Experiment 1, but did not take part in the previous experiment. Infants were rewarded with a T-shirt.

Stimuli

Visual stimuli were identical to Experiment 1. Audio stimuli consisted of the same six-sentence passages used in Experiment 1 containing a critical target word and the target words in isolation. Target words were *Löffel* 'spoon', *Nöffel*; *Mütze* 'hat', *Pütze*; *Sonne* 'sun', *Tonne*; and *Tasse* 'cup', *Fasse*.

Procedure

The procedure was identical to Experiment 1, except that similar-sounding words differed from familiarized words in the initial consonant rather than in the medial consonant.

Data analysis

Data analysis was identical to Experiment 1.

Results and discussion

Looking time to familiarization in Phase 1 was 100 seconds (*SE* 3.5) (7.2 trials, *SE* 0.5), ranging from 57 seconds to 122 seconds. Independent *t*-tests confirmed that familiarization length was not significantly different from Experiment 1 ($p > .5$). In Phase 2, mean looking times were 7.2 seconds (*SE* 0.6) for trials presenting sentences with similar-sounding words and 7.4 seconds (*SE* 0.6) for trials presenting sentences with phonologically unrelated words. Paired *t*-tests showed no significant difference between sentence types ($p > .6$). In Phase 3, mean looking time were 5.9 seconds (*SE* 0.7) for trials presenting similar-sounding words and 4.4 seconds (*SE* 0.5) for trials presenting phonologically unrelated words. Paired *t*-tests confirmed that looking times for similar-sounding words were significantly higher than looking times for phonologically unrelated words ($t(19) = 3.107$, $p < .01$), indicating that infants had a preference for similar-sounding words over phonologically unrelated words.

The results correspond to the findings of Experiment 1 and suggest an influence of phonological similarity on infants' segmentation behavior. Crucially, the results of Experiment 2 show that the findings from Experiment 1 are not restricted to onset-overlapping words. Rather, familiarity with a word seem to help infants segment similar-sounding words from speech regardless of the position of phonological overlap (see Mani, Durrant & Floccia, 2012, for similar results in phonological priming tasks with toddlers).

One might, however, argue that infants display a preference for the similar-sounding word (e.g. *Nöffel*) in Phase 3 simply because they have been exposed to a similar word in Phase 1 (e.g. *Löffel*), that is, that exposure to similar-sounding words embedded in sentences in Phase 2 is irrelevant for the observed effect in Phase 3. To address this objection, Experiment 3 tested whether infants show a preference for the similar-sounding words if they had *not* been exposed to these words in sentence context in Phase 2.

Experiment 3: Familiar word control

Experiment 3 differed from the first two experiments only in Phase 2: instead of hearing sentences with similar-sounding words, the infants were presented with sentences containing the familiar word. Note that in principle, one could also expose the infants to sentences containing completely different words in Phase 2 to control for the possibility that infants' preference for similar-sounding words in Phase 3 is not driven by exposure in Phase 1. We decided against using completely different words in Phase 2 in order to keep Experiment 3 more comparable to Experiments 1 and 2. In both previous experiments infants had heard the similar-sounding and phonologically unrelated words from Phase 3 in sentence context in Phase 2, giving both types of words a similar frequency of exposure before testing for infants' preference. Experiment 3 matched this procedure as closely as possible by presenting words in sentence context that differed only minimally from these words. Furthermore, this allowed us to use the exact same stimulus set as in Experiment 1, controlling for possible confounds that completely different words might introduce.

Phase 1 (familiarization) and Phase 3 (test) were identical to the previous experiments. If the preference for similar-sounding words in Experiments 1 and 2 is merely based on exposure in Phase 1, we expect a similar pattern of results in Experiment 3. In other words, if the familiarity effect for similar-sounding words in Phase 3 relies on a more general preference that carries over from familiarization in Phase 1, we expect to find a preference for the similar-sounding words in Phase 3 even when they are not presented in sentence context in Phase 2. If, however, the results of Experiments 1 and 2 are indicative of a segmentation advantage for words that sound similar to familiar words, we expect no preference for similar-sounding words over phonologically unrelated words in the current experiment as neither of them has been presented in sentence context in Phase 2.

Method

Participants

Twenty German monolingual 7-month-olds (12 boys) participated in the experiment. Their ages ranged from 6;09 to 7;26, mean age 7;03. Independent *t*-tests confirmed that their ages were not different from those of the infants participating in Experiments 1 or 2 ($p > .3$). Seven additional infants were tested but were excluded because of unwillingness to participate/failure to provide data for all three phases of the experiment (six) or looking times more than two standard deviations above the mean (one). Infants came from the same sample of families as infants from Experiments 1 and 2, but had not taken part in the previous experiments. Infants were rewarded with a T-shirt.

Stimuli

The stimuli were identical to Experiment 1.

Procedure

The procedure was similar to Experiments 1 and 2. Only the trials presented in Phase 2 differed in that they presented infants with sentences containing unfamiliar words and sentences containing the familiarized words from Phase 1 rather than words that sounded similar to the familiarized words.

Data analysis

Data analysis was identical to Experiment 1.

Results and discussion

Looking time to familiarization in Phase 1 was 102 seconds (*SE* 4.3) (6.6 trials, *SE* 0.5), ranging from 53 seconds to 126 seconds. Independent *t*-tests confirmed that familiarization length was not significantly different from Experiments 1 or 2 ($p > .4$). In Phase 2, mean looking times were 10.0 seconds (*SE* 1.0) for trials presenting sentences with familiar words and 10.8 seconds (*SE* 0.9) for trials presenting sentences with unfamiliar words. Paired *t*-tests showed no significant difference ($p > .4$). In Phase 3, mean looking times were 9.3 seconds (*SE* 1.5) for trials presenting similar-sounding words and 9.1 seconds (*SE* 0.9) for trials presenting phonologically unrelated words. Paired *t*-tests showed no significant difference between trial types ($p > .80$), indicating that infants had no preference for similar-sounding words over phonologically unrelated words.

The absence of a preference for similar-sounding words relative to phonologically unrelated words in Phase 3 in the current experiment provides further clarity regarding our interpretation of Experiments 1 and 2. In particular, Experiment 3 shows that exposure to the similar-sounding words in sentence context in Phase 2 is critical to elicit a preference for similar-sounding words later on: Experiment 3 differed from the previous two experiments only in that the similar-sounding words and the phonologically unrelated words were not presented in sentence context in Phase 2. Infants were familiarized with the exact same words (in Phase 1), but nevertheless fail to show a preference for similar-soundings words over phonologically unrelated words (in Phase 3). This indicates that exposure to a word in Phase 1 alone is not sufficient to create a preference for a similar-sounding word in Phase 3. Rather, exposure to the similar-sounding word in sentence context in Phase 2 is necessary, implying that the infants must have segmented the similar-sounding words from the sentences in Experiments 1 and 2. The findings from Experiment 3 thus suggest that the preference for similar-sounding words relative to phonologically unrelated words in Phase 3 (in Experiments 1 and 2) is not due to mere exposure to the familiar words in Phase 1, but instead relies on the segmentation advantage for words that sound similar to familiar words in Phase 2. Familiarity with a word in Phase 1 appears to ease infants' segmentation of similar-sounding words in Phase 2 (in Experiments 1 and 2) such that infants are better able to recognize these words in isolation in Phase 3. The absence of such segmentation exposure (in Phase 2) in the current experiment leads to no preference for similar-sounding over unrelated words in Phase 3.

Our results, however, contrast with previous findings by Jusczyk and Aslin (1995), namely that infants listen longer to sentences containing familiar words relative to sentences containing unfamiliar words. We did not find such a preference in Phase 2 of the current experiment. Yet, we note that the absence of such a segmentation effect in Phase 2 is in line with previous studies with infants from language backgrounds apart from American English. For instance, Goyet, de Schoenen and Nazzi (2010) show that French 12-month-olds do not show this word segmentation effect despite displaying evidence of segmenting words from a fluent speech stream in other more sensitive tasks, e.g. ERP tasks (for similar results with Dutch infants see Kooijman, Johnson & Cutler, 2008). Note that we also used a different procedure from most previous segmentation studies which might lead to attenuated results. While most studies use the Head-Turn-Preference procedure, we used a modified version of the preferential looking task that is often used in phoneme discrimination studies (e.g. Maye, Werker & Gerken, 2002). While the rationale behind the two paradigms is similar, the required overt response is different and visual fixation times might be more variable than head turns in young infants. It has been argued elsewhere that visual preference depends on several factors such as, for example, previous familiarization time and that a lack of preference does not necessarily imply a failure to distinguish between two types of stimuli (for a discussion see Houston-Price & Nakai, 2004). Thus, infants might be able to segment words from a fluent speech stream without showing an overt behavioral response, indicating that they have segmented these words (see also Aslin & Fiser, 2005). In other words, we do not conclude from the absence of a significant difference in Phase 2 that infants did not segment the familiarized words from fluent speech in this experiment. Infants might have segmented these words without showing an overt preference in Phase 2. Importantly, however, for the purposes of the current study, the fact that infants do not show a preference for similar-sounding words in Phase 3 in the current experiment ensures that the preference found in Experiments 1 and 2 is not driven by exposure in Phase 1 alone.

General discussion and conclusion

The current study provides evidence that familiarity with a word can help infants isolate similar-sounding words from fluent speech: infants prefer words that they have heard in sentence context if these words sound similar to familiar words, but not if they are phonologically unrelated to familiar words.

So what does the preference for similar-sounding words over unrelated words (in Experiments 1 and 2) reveal about infants' segmentation behavior? Experiment 3 ruled out the possibility that infants' preference for similar-sounding words carries over from the initial familiarization phase: infants did not prefer similar-sounding words over unrelated words when they had not been presented with these words in sentence context in Phase 2. Thus, initial familiarization with a word is not sufficient to elicit preference for a similar-sounding word. Rather, exposure to the similar-sounding word (in sentence context) seems to be necessary. However, both types of words – similar-sounding and phonologically unrelated words – had been presented in sentence context in Phase 2 in Experiments 1 and 2. Nevertheless, infants showed a preference for listening to similar-sounding words relative to unrelated words in Phase 3. This could mean that they recognized only the similar-sounding words, but not the phonologically unrelated words in Phase 3. This explanation would suggest that infants were only able to segment the similar-sounding words from sentences (in Phase 2), leading to better encoding of and preference for these words (in Phase 3). But it might also be that they segmented both types of words equally well but nevertheless have a preference for listening to the similar-sounding words later in isolation, in other words that they recognize these words *better*.

Thus, infants familiarized with a word might be better able to segment similar-sounding words from fluent speech and/or be better able to recognize similar-sounding words when presented later in isolation.

Either way, this highlights a powerful bootstrapping mechanism enabling young children to use their existing vocabulary to good advantage to segment and encode novel words that sound similar to words known to them. More specifically, infants might detect similar-sounding words based on the phonological overlap with familiar words. In the current study, infants' recent exposure to a word such as *Löffel* might lead to the constituent sounds of this word being more active. This might help infants to recognize these sounds in the similar-sounding word *Löckel* presented in sentence context and enable the infant to better segment this word. This in turn would lead to infants showing a preference for similar-sounding words in Phase 3. Thus, the effect might be driven by low-level phonological activation and rely on a process similar to the one that has been proposed to explain phonological facilitation effects observed in toddlers (see Mani & Plunkett, 2010).

As one reviewer pointed out, one might alternatively interpret our findings as an effect of short-term phonotactic exposure, that is, during the experiment the phonotactic probability of similar-sounding words such as words ending with '-*öffel*' is increased leading to better segmentation and recognition of these words (for the influence of phonotactic knowledge on segmentation see, e.g. Saffran *et al.*, 1996; Jusczyk *et al.*, 1999). Since we familiarized infants with a word at the beginning of the experiment in order to establish familiarity, it remains open whether a segmentation advantage only applies to words that infants have recently been exposed to or whether it also applies to words that are stored in infants' long-term memory. It would therefore be interesting to replicate our study using words that infants are very likely to know and words that infants are unlikely to know (i.e. relying on infants' previous knowledge rather than familiarizing the infant at the beginning of the experiment). Yet, we suggest that our results are not bound to recently heard words, but that a similar mechanism (as outlined above) is at play for words that sound similar to previously learned words in the infant's lexicon. Singh *et al.* (2008) find that infants find it easier to recognize highly frequent words in sentence context when they are altered in pitch, that is when their surface characteristics change, compared to words that they do not know. This suggests that infants can use stored knowledge to detect phonological similarities between words. While Singh *et al.*'s (2008) study shows infants' ability to use this knowledge to abstract away from surface variability, that is to detect the same word under different speaking conditions, our study broadens this finding and suggests that phonological similarity might also help infants to detect novel words. Furthermore, our results parallel findings with older children that words that sound similar to familiar words are learned faster and more robustly (Storkel, 2001; Storkel & Hoover, 2011; Newman *et al.*, 2008). In the context of word learning, it has been argued that words that sound similar to known words have a processing advantage. In particular, new words that overlap phonologically with familiar words are considered to be easier to process because they receive support from stored phonological representations (cf. Storkel, 2001). A similar mechanism might be at play in the current study – familiarity with a word-form leading to infants segmenting similar-sounding word-forms with greater ease.

Note, however, that there is evidence that learning a new word is hindered when the infant already knows a similar-sounding word (Swingley & Aslin, 2007), suggesting that the familiar word interferes with learning. Similarly, Hollich, Jusczyk and Luce (2002) found that listening to a set of novel words inhibited later learning of a new label that was phonologically similar. This effect appeared only when the infants repeatedly listened to the novel words – when they heard the word once, label learning was facilitated rather than hindered, suggesting that familiarity with the phonological make-up of a word can support learning. These conflicting results might be reconciled following a proposition of Storkel, Armbrüster and Hogan (2006) who argue that phonological similarity between words influences different aspects of learning. While phonological probability triggers learning, neighborhood density mainly affects the integration of new words into the lexicon. Thus, familiarity with a word might help to spot a similar-sounding word in the speech stream and trigger sensitivity to its phonological form although this might later hinder its successful integration into the lexicon because it is similar to a known word. Furthermore, the findings that phonological similarity hinders word learning come from toddlers and older children. It might be that at the very early stages of language learning in infancy, interference from phonological similarity is reduced. This might be because the infant knows fewer words, thereby reducing the detrimental impact of phonological neighbors on lexical learning. Indeed, phonological neighbors do not interfere with word recognition in toddlers younger than 2 years of age (Mani & Plunkett, 2010), suggesting that competition effects based on phonological similarity are limited in young infants.

Some computational models also stress the role of lexical knowledge in speech segmentation and suggest that the main determinant of segmentation at the earliest stages might be experience with particular, similar-sounding words (e.g. Brent, 1997; Gambell & Yang, 2005). We do not want to dismiss the influence of phonotactic or prosodic knowledge in segmentation. Rather we suggest that phonological similarity to known words might provide another useful cue to segmentation and bootstrap recognition of novel words. For instance, the INCDROP model of speech segmentation (Brent, 1997) suggests that listeners parse the speech stream into familiar and novel word-like units: when the infant has learned a word such as *big*, she will be able to recognize *big* from the utterance '*bigdog*' and extract *dog* as a possible new word (see also Gambell & Yang, 2003; Dahan & Brent, 1999; Bortfeld *et al*., 2005; Cunillera *et al*., 2010). This might sometimes lead to wrong segmentations (such as 'I was have' from be-have, cf. Peters, 1983), but is nevertheless a valid strategy. Following a similar mechanism, some words might be spotted more easily in the speech stream because of their overall phonological similarity with existing lexical items. This would give these similar-sounding words a segmentation advantage compared to words that are not phonologically related to a familiar word.

In conclusion, the results of the current study suggest that familiarity with a word helps infants segment similar-sounding words from fluent speech. Thus, aside from statistical and phonological knowledge about sound patterns, familiar words might also help infants to isolate novel words from the speech stream. This would provide infants with a powerful mechanism to bootstrap word learning and might provide an explanation for the finding that early vocabularies tend to contain dense neighborhoods (Coady & Aslin, 2003; Storkel, 2004): words that sound similar to existing familiar words are easier to spot in utterances and thereby get a head start in lexical learning.

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