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Isolated Words Selectively Enhance Memory for High Transitional Probability Sound Sequences

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To the Graduate Council:

I am submitting herewith a thesis written by Ferhat Karaman entitled "Isolated Words Selectively Enhance Memory for High Transitional Probability Sound Sequences." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Experimental Psychology.

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Isolated Words Selectively Enhance Memory for High Transitional Probability Sound Sequences

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Abstract

Research over the past two decades has demonstrated that infants are equipped with remarkable computational abilities that allow them to find words in continuous speech. Infants can encode information about the transitional probability (TP) between syllables to segment words from speech when tested immediately after familiarization with an artificial (e.g., Saffran, Aslin & Newport, 1996) or natural language (Pelucchi, Hay, & Saffran, 2009). However, infants' ability to retain the sequential statistics beyond the immediate familiarization context remains unknown. In the present study, we examine infants' memory for statistically-defined words 10-minutes following familiarization with a naturally produced Italian corpus. Eight-month-old English-learning infants were familiarized with Italian sentences that contained four embedded target words (see Pelucchi et al., 2009): two words had high internal TP (HTP, TP=1.0) and two had low TP (LTP, TP=.33) and were tested on their ability to discriminate HTP from LTP words using the Headturn Preference Procedure. When discrimination was tested following a 10-minute delay, infants listened equally to HTP and LTP words, suggesting that memory for statistical information likely decays over even short delays (Experiment 1). Experiments 2-4 were designed to test whether experience with isolated words selectively reinforces memory for statistically-defined words. When 8-month-olds were familiarized with the same corpus and then were given experience with the isolated words immediately after familiarization, they looked significantly longer to HTP words than LTP words after the 10-minute delay, suggesting that the experience with isolated words may reinforce memory for HTP words following a delay.

Table of Contents

Chapter 1

Introduction

Languages are vastly complex systems and yet most children seem to acquire their native language with little apparent effort. Most speech input infants hear consists of continuous streams of sounds with few pauses between words. Further, the beginnings and ends of the sounds that form words are not clearly signaled by any infallible acoustic cues (Thiessen & Saffran, 2003). Therefore, identifying words in a continuous stream of speech in the absence of robust and reliable cues to word boundaries is a difficult problem for language learners (Aslin & Newport, 2008; Endress & Hauser, 2010). Despite the substantial richness and complexity of linguistic input, infants learn how to break the continuous speech stream into discrete units – words – with remarkable speed. So, how do they accomplish such a difficult task so rapidly? One promising potential mechanism underlying early language acquisition is statistical learning, the process of extracting statistical and structural information from the environment by tracking regularities present in the input.

Over the past two decades, statistical learning has received a great deal of attention in the area of early language acquisition for its potential to support infants' discovery of statistical regularities in linguistic input (e.g., Saffran, Aslin, & Newport, 1996; Aslin, Saffran, & Newport, 1998; Saffran, Johnson, Newport, & Aslin, 1999). There is a substantial body of research suggesting that infants are powerful statistical learners. Several studies have demonstrated that infants encode information about the transitional probability (TP, the probability of *X* given *Y* in the sequence *XY*) between syllables to segment words from a speech stream when tested immediately after familiarization with an artificial (e.g., Saffran et al.,1996) or natural language (Pelucchi, Hay, & Saffran, 2009a; Pelucchi, Hay, & Saffran, 2009b). However, extracting words from speech may be of little help building a vocabulary unless infants encode the sound patterns of these words into long-term memory and remember them over time and in a variety of different contexts. The problem is that infant statistical learning is typically assessed immediately after familiarization with a speech stream, and thus we do not know whether infants derive benefit from their experience with sequential statistics beyond the immediate testing session.

Only a handful of studies have examined what infants remember about newly learned words over time (e.g., Houston & Jusczyk, 2003; Jusczyk & Hohne, 1997), and, to our knowledge, none have examined infants' memory for statistically defined words. If syllables that tend to co-occur have a privileged status when infants next encounter them, then subsequent language learning might be facilitated. In the present study, we assess infants' long-term memory for statistically-defined words following familiarization with a naturally produced Italian corpus.

Memory processing in infancy

Memory is fundamental to cognition and it is crucial for our everyday lives (Bauer, 2007; Johnson & De Haan, 2015). In fact, memory is not a single simple faculty but consists of different systems such as working memory/short-term memory and long-term memory. Even within each system, there are different types of memory. For example, long-term memory is usually classified as being either explicit memory and implicit memory (Graf & Schacter, 1985). Explicit (or declarative) memory is generally defined as a memory that can be intentionally and consciously recalled. Whereas implicit (or procedural) memory is an experiential or functional form of memory that cannot be consciously controlled (Graf & Schacter, 1985). Although both explicit and implicit memory appear to be functional early in development (Rovee-Collier, 1997; Rovee-Collier & Cuevas, 2009), they appear to vary somewhat in their developmental time course. For example, the brain regions associated with explicit memory (i.e., medial temporal lobe involving the dentate gyrus of hippocampus) are not fully developed until approximately 3 years of age, whereas the brain mechanisms serving implicit memory, including the cerebellum, basal ganglia, and inferior frontal gyrus, are functional from birth (Drummey & Newcombe, 1995).

Implicit memory and language learning mechanisms share similar underlying neural mechanisms and cognitive underpinnings (e.g., perceptual learning, sequential learning; Ettlinger, Margulis, & Wong, 2011). For example, one form of implicit memory involves the implicit learning of sequences (e.g., statistical learning in the context of language learning). When we consider the situation of infants learning to segment the speech stream, it seems almost impossible to explicitly teach a baby to break up the continuous speech into individual words by tracking statistical regularities in speech. Thus, like the implicit memory system, statistical language learning is based on the idea that infants can track the sound sequences without explicit awareness (Ettlinger, Margulis, & Wong, 2011). Furthermore, brain imaging studies have recently revealed that similar neural substrates, including the basal ganglia (Mestres-Missé, Càmara, Rodriguez-Fornells, Rotte, & Münte, 2008), the inferior frontal cortex (McNealy, Mazziotta, and Dapretto, 2006), and the superior temporal gyrus (Geschwind, 1970; Leonard, Bouchard, Tang, & Chang, 2015) support both language learning and implicit memory.

In addition to their being multiple types of long-term memory systems, each types of memory involves a collection of various sub-processes including encoding, consolidation, storage and retrieval (Straube, 2012). Encoding – initial registration of information (i.e., perceptual processing) in the brain – is closely associated with learning and long-term retention of information (see Bauer, 2002, 2004, 2006, 2007 for reviews). Although the term ‘encoding’ is not commonly used by infant language researchers, it has been well-established that even young infants may encode various types information available in the linguistic input such as phonological features and statistical regularities (Saffran, et al., 1996; Nazzi, Bertoncini & Mehler, 1998). However, and especially for infants, even once a memory has been successfully encoded it remains vulnerable to forgetting (Vlach & Sandhofer, 2012; Horst & Samuelson, 2008). Thus, after encoding, consolidation and storage are required for long-term retention (Davis, Di Bietta, Macdonald, & Gaskell, 2009). Neurologically, while explicit memory consolidation relies on the hippocampus (Gais & Born, 2004), implicit memory consolidates in the cerebellum, basal ganglia, and amygdala (Levin, 2011). Although it is clear that when memories are consolidated, they become less susceptible to forgetting, the role of consolidation and mechanisms involved are not entirely clear (Wojcik, 2013). Neuroscience has revealed that there two general types of consolidation: 1) a rapid initial process that occurs at the level of the synapse within the order of minutes (i.e., synaptic consolidation) and 2) more prolonged process that is related to distributed neural systems and that occurs when information is transferred from the hippocampal formation to the cortex during sleep and rest (i.e., systems consolidation) taking hours or even days (Dudai, 2004; Bramham & Messaoudi, 2005; Clopath, 2012; Winocur, Moscovitch, & Bontempi, 2010).

The final memory process is called retrieval, which is bringing memory out of the storage. While explicit memory retrieval is revealed by intentional re-activation of information which has been previously encoded and stored in the brain, implicit memory retrieval occurs without conscious awareness and is revealed by facilitation of performance on a task (Graf & Birt, 1996). Neurologically, implicit and explicit memory retrieval also appear to be correlated with distinct brain activation patterns (Bäckman et al., 1997).

In the infant memory literature, explicit and implicit memory retrieval have been operationalized in terms of performance on different kind of memory tasks. Since young infants are not capable of speaking, most memory tasks commonly used with adults and children are not appropriate for young infants. There are only a few memory tasks that can be used to assess the memory abilities in pre-verbal infants. The mobile-kicking task (or infant operant conditioning paradigm) and the deferred imitation task were commonly used to examine early memory (Rovee-Collier, 1999). For example, in the deferred imitation paradigm, infants watch an adult manipulate an object and then the infants' ability to imitate those actions is assessed following a specified delay. Because infants' imitations are based on observation of actions, the deferred imitation paradigm is thought to assess explicit memory in particular (Rovee-Collier, 1999). A few studies of early language acquisition, however, have employed the Headturn Preference Procedure to investigate pre-verbal infants' implicit memory traces of phonological and indexical properties of words (Houston & Jusczyk, 2003; Jusczyk & Hohne, 1997). These studies will be reviewed in the following section.

Incorporating memory processes in the study of early language acquisition

Since memory is a fundamental cognitive capacity that plays a central role in language acquisition, incorporating memory processes in the study of early language acquisition is very important (see Wojcik, 2013 for a recent review on early memory mechanisms supporting word learning). Even though the encoding, storage, consolidation, and retrieval of information from memory are crucial for understanding the process of language acquisition, most infant language researchers do not investigate memory. There have been only a few studies addressing the question of whether infants remember spoken words. For example, Houston and Jusczyk (2003) examined 7.5-month-old infants' long-term memory for the phonological patterns of words using the Headturn Preference Procedure. Infants were familiarized with target words (i.e., ‘cup’ and ‘dog’ or ‘feet’ and ‘bike’) for 30 seconds each. When tested 24-hour later for their orientation times to passages, 7.5-month-olds listened significantly longer to the passages containing familiarized words than to similar passages containing novel target words, suggesting that infants appear to remember some phonological patterns even after a 1-day delay.

In another study, Jusczyk and Hohne (1997) investigated 8-month-olds’ long-term retention of the sound patterns of words by exposing them to audio recordings of children’s stories for ten days over a two-week period. Following a subsequent 2-week delay, infants were presented a list of words that either occurred frequently (i.e., story words) or did not occur (i.e., foils) in the stories and tested on their memory for these words. The infants who had heard the stories listened significantly longer to the words from the stories than to the foils. However, a control group who had not heard the stories showed no such preference for either story words or foils. Thus, the findings suggest that the 8-month-old infants who had heard the stories were able to segment and remember the frequently occurring words in the stories even after 2-weeks delay.

Both of these studies focused on the words’ phonetic characteristics and frequency of occurrence in the language. Successful encoding and retention of information over time may have been driven by differences in the frequency of occurrence between target words and foils. Further, as many of the words used in the studies by Jusczyk and colleagues (Houston & Jusczyk, 2003; Jusczyk & Hohne (1997) were likely familiar to infants of this age (Bergelson & Swingley, 2012), it is unclear whether infants would also exhibit memory for newly segmented novel words.

There is some evidence to suggest that infants can also remember sequential order information (Mandel, Nelson, & Jusczyk, 1996; Benavides & Mehler, 2015; Gulya, Rovee-

Collier, Galluccio, & Wilk, 1998; Leslie & Keeble, 1987). For example, Mandel and colleagues (1996) used a high-amplitude sucking procedure to investigate whether 2-month-old infants can remember the detect changes in in the sequential order of words in a spoken sentence after a 2-minute delay. Results revealed that infants' retention of the sequential order of words was better when words were produced as a single, well formed utterances than if the same words were produced in a list or as two sentences. Sequential order information is fundamentally similar to transitional probabilities. Thus, it is plausible to assume that infants can also store the sequential statistics of speech in long-term memory.

Chapter 2

Current Study

In the present study, we sought to explore the role that a different type of statistic – namely, word internal sequential statistics – plays in infants' memory for recently heard words. In order to explore infant's memory for statistically defined words, we decided to use natural language materials that have been used successfully for a number of other studies on statistical learning (see Hay, Pelucchi, Graf Estes, & Saffran, 2011; Lew-Williams et al, 2011; Pelucchi et al., 2009a; 2009b). Here, and in these previous studies, infants were presented with a series of Italian sentences in which four target words (i.e., *fuga*, *melo*, *casa*, & *bici*) were incorporated. Two of the words were high TP (HTP; TP = 1.0) because their syllables did not occur anywhere else in the corpus and two of the words were low TP (LTP; TP = 0.33) because the first syllable occurred in other words throughout the corpus. If infants are able to track the transitional probability between syllables when faced with natural language input, following familiarization, they should show differential interest in words with strong versus weaker co-occurrence patterns. Italian was selected as the familiarization language because it shares a number of phonological and prosodic features with the infants' native language, English, yet is sufficiently unfamiliar to infants such that they would not be able to use known words to segment the language.

In the original studies using natural language materials, 8-month-old infants were familiarized with approximately 2 minutes of a natural Italian corpus and were immediately tested using Headturn Preference Procedure on their ability to differentiate HTP from LTP words (Pelluchi et al., 2009a, 2009b). In these types of statistical learning studies, learning is evidenced by differential interest in words with strong versus less strong internal statistics. In Pelucchi et al.'s (2009a) original study, and in much of their subsequent work using these types of Italian stimuli, infants showed a significant listening preference for HTP words over LTP words. Familiarity preferences suggest that infants have tracked the statistical regularities in the corpus and remain interested in listening words that are more familiar due to their strong internal statistics. These findings, that infants can track TP to find words in these types of Italian corpora, have been replicated a number of times over the past few years (Hay et al., 2011; Lew-Williams et al., 2011; Pelucchi et al., 2009a; 2009b).

Despite these important findings, little is known about infant's memory for statistically defined sound sequences, which is a critical shortcoming of the literature. Studies of statistical learning have yet to explore the relationship between tracking the statistical regularities of sounds and remembering those regularities over time and in variety of different contexts. So far, infant statistical learning has primarily been assessed immediately after familiarization with a speech stream. However, Akhtar and colleagues have demonstrated that a large portion of early language input comes from overheard speech (Akhtar, 2005; Akhtar, Jipson, & Callanan, 2001), where objects and concepts may not be in the infant's immediate environment. Thus, it may be advantageous for infants to remember the sound patterns of words that they have extracted from continuous speech. Demonstrating that infants are able to encode sequential statistics into memory and remember them over time will support theories of statistical learning as a mechanism by which infants acquire language.

In the present study, we imposed a 10-minute delay between familiarization and test. Since infants are not presented with familiarization language and target words throughout the 10-minute delay interval, the delay between the end of familiarization and the first test trial exceeds the duration of working memory in such young infants (Alan W. Kersten, personal communication). Thus, successful discrimination of HTP from LTP words following this delay would likely be based on retrieval from long-term memory. Also, it is important to emphasize that infants are actively playing with toys the 10-minute delay interval and are only hearing minimal speech. One might argue that infants are actively processing and strategically rehearsing the words in working memory during the10-minute delay, in which case they might be able to retain them in working memory for longer period of time. However, since 8-month-olds are not capable of rehearsal or other ways of keeping the stimulus active, after 10-minute delay, the only way they would recognize words would be if it had been encoded into, and retrieved from, long-term memory.

Experiment 1

As indicated above, no studies to date have examined infants' memory for statistically defined sound sequences. Do infants' memories for statistically defined sound sequences persist beyond the immediate experimental session? In order to address this issue, in the current experiments we examined the longevity of statistical learning by testing infants' ability to encode the sound patterns of words extracted from continuous speech into memory and remember them over time. In Experiment 1, twenty-four 8-month-old infants were first familiarized with a naturally produced Italian speech used by Pelucchi and colleagues (2009) and tested on their ability to discriminate words with high and low TP following a 10-minute delay. Based on the findings of Pelucchi et al. study, using the same familiarization materials, a familiarity preference is our index of learning. We predicted that 8-month-old infants would show a listening preference for HTP compared to LTP words after a 10-minute delay.

Methods

Participants. Twenty-four healthy and full-term infants (8 males and 16 females) with a mean age of 8.4 months (range = 8.1 to 8.9) participated in Experiment 1. Infants were from monolingual English-speaking families and had no history of hearing or vision impairments, and no prior exposure to Italian or Spanish. Half of infants were randomly assigned to a counterbalanced language where the HTP and LTP words were switched.

Participants were recruited through the Child Development Research Group database maintained in the Department of Psychology at the University of Tennessee, Knoxville, and through community outreach initiatives in the greater Knoxville area. Twelve additional infants were tested but not included in the analyses for the following reasons: excessive fussiness (n = 11) or not paying attention (n = 1). Parental consent was obtained for all participants. For their participation, all infants were given a small gift.

Stimuli. Speech stimuli were identical to those used successfully in a previous study of word segmentation (Pelucchi et al., 2009a; Experiment 3). The familiarization corpus consisted of 12 grammatically correct and semantically meaningful Italian sentences produced with lively prosody by a female native speaker of Italian (see the Appendix for sentence lists). All sentences were matched in intensity to be presented at approximately 65 dB_{SPL}. Infants were exposed to one of the two counterbalanced languages 3 times during familiarization for a total duration of 2 minute 15 seconds.

Four bisyllabic target words (*bici*, *casa*, *fuga*, and *melo*) were embedded in the speech stream. These target words were phonetically and phonotactically legal in English and all followed a strong/weak (trochaic) stress patterns. The target words appeared with equal frequency, occurring six times in each corpus, but their internal TPs differed. In Language A, the syllables *fu, ga*, *me*, and *lo*, appeared only in the words *fuga* and *melo*. Therefore, the internal TPs of *fuga and melo* were 1.0 (*HTP words*). However, the internal TPs of the other two target words (*bici* and *casa)* were lowered to 0.33 (*LTP words)* by adding 12 additional occurrences of their first syllable throughout the corpus. Language B had the same structure but the HTP and LTP words were switched. The target words were matched in length (750ms) and intensity (65 dB_{SPL}), while keeping their original pitches.

Procedure. Experiment 1 consisted of three phases: familiarization phase (2 min 15 sec), a 10-minute delay phase, and a testing phase. Infants were tested using the Head Turn Preference Procedure (HTPP) as adapted by Saffran et al. (1996). Infants were seated on a caregiver's lap inside a soundproof booth that was equipped with a center monitor and two side monitors and two side audio speakers. The caregiver listened to masking music over headphones to reduce the potential for bias. The experimenter observed the infants' looking behavior in a control room via a closed circuit camera. During familiarization, we sought to use a visual stimulus that was as similar as possible to those used in the original studies by Pelucchi and colleagues (2009a; 2009b). However, because our booth was equipped with monitors instead of actual bike lights, we used a video of the original flashing lights instead of actual flashing lights. During familiarization, a video of flashing light was presented on the monitors contingent upon the infants' looking behavior (as in the test phase described next), while one of the two counterbalanced languages played continuously from the speakers beneath the side monitors.

After the familiarization phase, infants were given a 10-minute break before the testing phase began. During the 10-minute delay, infants were allowed to play with toys in the laboratory waiting room, while the caregiver filled out a demographic information questionnaire and a Communicative Development Inventory (CDI) and the experimenter set up for the test trials. While the infant was playing with toys in waiting room, none of the familiarization languages or test words were presented. Following the 10-minute delay, infants and parents returned to the testing room, where infants were presented with the test phase. All infants heard the same 12 test trials regardless of familiarization condition – two HTP word trials and two LTP word trials were presented three times, randomized by block. Each test trial began with a video of a centrally-presented spinning pinwheel. Since infants were coming back into the booth after the 10-minute delay, we wanted to use a somewhat more engaging visual stimulus, a video of a spinning pinwheel, to help them to maintain attention throughout the test. Once the infant had fixated the pinwheel, the center monitor was extinguished and the pinwheel appeared on one of the two side monitors. When the infant made a headturn of at least 30^{o} in the direction of the pinwheel, one of the four target words played continuously in isolation until the infant looked away for 2 seconds or until 15 seconds has elapsed. Thus, the infant essentially controlled how long he or she heard the target word. This procedure was repeated until the infant had completed all 12 test trials. Trials with total looking time that was less that one second were automatically repeated at the end of the test session. The dependent measure was the amount of time the infant oriented toward each type of test stimuli.

Results and Discussion

We first compared the two counterbalanced languages to see if there were any listening preferences for any of the target words. As there were no significant difference scores for the counterbalanced languages, t (22) = 1.27, p = .78, d=.52, result from the two languages were collapsed in the subsequent analysis. A paired samples t-test (all t-test were 2-tailed) revealed that infants listened equally to HTP words (M = 9.59 s, SE = .46) and LTP words (M = 9.63 s, SE = .47), t (23) = .095, p = .93 (see Figure 1), after the 10-minute delay. These results suggest that memory for statistical information may decay over even short delays.

Why did the infants in Experiment 1 fail to demonstrate retention of the statistically defined words? In order to efficiently retrieve the statistical properties of words from memory, infants must first robustly encode those patterns. However, brief exposure to a complex natural language may in and of itself not be sufficient to facilitate the encoding of words' statistical properties. Novel words may not engender such strong representations, without additional support. We know that infants can take advantage of multiple cues (e.g., transitional probabilities, isolated words, stress patterns) during speech segmentation (Thiessen & Saffran, 2003; Lew-Williams at al, 2011). Although the majority of speech infants hear is continuous in nature, a portion of the input infants hear comes in the form of isolated words (Brent & Siskind, 2001; Fernald & Morikawa, 1993; Fernald & Hurtado, 2006). For example, Fernald & Morikawa (1993) and Brent & Siskind (2001) have demonstrated that an average of 9% of utterances produced by caregivers consists of isolated words. Further, recent work by Lew Williams and colleagues (Lew-Williams at al, 2011) suggests that hearing words in isolation facilitates statistical learning. In their study, 8- to 10-month-old infants were familiarized with a somewhat shorter natural Italian corpus that contained either fluent speech only or a combination of fluent speech and isolated words. Although experience with the isolated words may have reduced the difference in TP between the HTP and LTP words, infants none-the-less successfully discriminated HTP from LTP words when words appeared both in fluent speech and in isolation (Lew-Williams et al., 2011). They failed to discriminate the HTP and LTP words when the words were only presented within the shorter fluent speech stream. Thus, isolated words appear to support, rather than interfere with statistical learning. Based on this work, in Experiment 2 we ask whether isolated also support memory for statistically defined words that have been segmented from the speech stream.

Experiment 2

Experiment 2 was designed to investigate whether experience with isolated words can selectively reinforce infants' memory for statistically defined words. If having experience with the isolated words immediately following familiarization with a speech stream selectively supports memory for HTP words, then we would expect infants to listen longer to HTP than LTP words following the 10-minute delay.

Twenty-four 8-month-old infants were familiarized with the same Italian corpus and tested immediately following familiarization (T1) and were then tested again following a 10-minute delay (T2). The basic rationale behind testing infants immediately following familiarization was to allow them to have experience with isolated words. Since language acquisition is fundamentally dynamical process, allowing infants to self-select which words they hear might better support learning. One of the main advantages of using an infant-controlled paradigm is that it takes into account infants' individual processing and encoding abilities because one infant may need more time to process the information presented than other. Also, when infants are allowed to choose what they are paying attention to, they seem less likely to become fussy. Using an infant-controlled procedure at T1 would also allow us to verify that we could replicated previous studies in the new laboratory set-up.

Methods

Participants. Twenty-four healthy and full-term infants (13 males and 11 females) with a mean age of 8.4 months (range = 8 to 8.9) participated in Experiment 2. Infants were from monolingual English-speaking families and had no history of hearing or vision impairments, and no prior exposure to Italian or Spanish. Half of infants were randomly assigned to a counterbalanced language where LTP and HTP words were switched.

Participants were recruited through the Child Development Research Group database maintained in the Department of Psychology at the University of Tennessee, Knoxville, and through community outreach initiatives in the greater Knoxville area. Thirteen additional infants were tested but not included in the analyses for the following reasons: excessive fussiness (n = 9), not paying attention (n = 1), or experimental error (n = 3).

Stimuli. The stimuli were the same as those used in Experiment 1.

Procedures. Procedures were similar to those of Experiment 1, with the following exceptions: 1) infants were tested both immediately after familiarization and after a 10-minute delay, 2) because infants tended to get bored easily and 'fuss out' of the experiment, we employed different visual stimuli in the first and second sessions of the experiment. During the familiarization phase and immediate testing phase (T1), a video of flashing lights was presented on the side monitors contingent upon infants looking behavior. However differently, during delayed testing phase (T2), a video of spinning pinwheel was presented to capture infants' attention. As in the previous experiment, infants played with toys in laboratory waiting room during the 10-min delay.

Results and Discussion

As in Experiment 1, we first compared the two counterbalanced familiarization languages for both the immediate testing phase and delayed testing phase. As there were no significant difference scores for the counterbalanced languages in the immediate testing phase, t (22) = 1.13, p = .26, or in the delayed testing phase, t (22) = .46, p = .65, the two conditions were combined in all subsequent analyses.

Surprisingly, paired samples t-test showed that infants failed to discriminate HTP words (M = 7.85 s, SE = .44) from LTP words (M = 8.25 s, SE = .45), t (23) = .73, p = .47 (see Figure

1), when tested immediately after familiarization. However, the same infants looked significantly longer to HTP words (*M* = 9.71 s, *SE* = .46) than LTP words (*M* = 8.69 s, *SE* = .46) after the 10-minute delay, t (23) = 2.8, p = .01, d = .6 (see Figure 1). At T2, 17 out of the 24 infants listened longer to the HTP words. Importantly, there were no significant correlations between listening preferences at T1 and T2, r = .18, n = 24, p = .4, suggesting that individual differences in experience with the isolated words at T1 did not impact infants' preferences for HTP words at T2. Together with the results from Experiment 1, the current study suggests that experience with isolated words appear to selectively reinforce memory for high transitional probability words. These results are consistent previous research suggesting that experience with isolated words may facilitate statistical learning (Lew-Williams et al., 2011).

It is worth noting here that infants did not appear to discriminate HTP from LTP words when they are tested immediately following familiarization. Thus, we failed to replicate the familiarity preference for HTP words seen in previous studies (Pelucchi et al., 2009a; 2009b). It is certainly the case that the present study and Pelucchi et al.'s (2009) original studies were conducted on different populations in different laboratories using the slightly different methodologies. For example, to capture infants' attention, Pelucchi et al.'s (2009) original study used actual flashing light whereas, in the present study, we used a video of flashing light. Failure to replicate previous studies is a pervasive, yet underreported, in psychological research (Open Science Collaboration, 2015).

Experiment 3

To explore whether methodological factors might account for infants' failure in Experiment 2 to differentiate HTP from LTP words immediately after familiarization, in Experiment 3, a new group of 8-month-olds was familiarized with the same corpus and tested immediately after familiarization while watching more engaging visual stimuli, a video of a spinning pinwheel.

Methods

Participants. Twenty-four healthy and full-term infants (9 males and 15 females) with a mean age of 8.4 months (range = 8 to 8.7) participated in Experiment 3. Infants were from monolingual English-speaking families and had no history of hearing or vision impairments, and no prior exposure to Italian or Spanish. Half of infants were randomly assigned to a counterbalanced language where LTP and HTP words switched.

Participants were recruited through the Child Development Research Group database maintained in the Department of Psychology at the University of Tennessee, Knoxville, and through community outreach initiatives in the greater Knoxville area. Seventeen additional infants were tested but not included in the analyses for the following reasons: fussiness (n = 13), not paying attention (n = 2), or experimental error (n = 2).

Stimuli. The auditory stimuli were the same as those used in Experiment 1. A video clip of a spinning pinwheel was during both the familiarization and testing.

Procedures. Experimental procedures were similar to those of Experiment 1 and 2. In Experiment 3, infants were familiarized with the same corpus and tested only immediately following familiarization while watching a video of a spinning pinwheel on the monitors.

Results and Discussion

As in previous experiments, we first compared the counterbalanced languages. As there were no significant difference scores for the counterbalanced languages, t (22) = .22, p = .71, d = .83, the two conditions were combined in the subsequent analysis. A paired sample t-test revealed that infants readily discriminated HTP (M = 9.23 s, SE = .37) from LTP (M = 8.17 s, SE

= .31) words, t (23) = 3.68, p = .001, d = .8 (see Figure 1), suggesting that performance at T1 in Experiment 2 may reflect methodological differences unrelated to the learning task or a Type 2 error (failure to find a true effect). This matter will be further discussed in the general discussion section.

Experiment 4

The results of Experiment 2 are clear: Having experience with isolated words during immediate testing phase (T1) appears to reinforce their memory for HTP words at delayed testing phase (T2). Although listening preferences following the 10-minute delay were not correlated with listening preferences for isolated words immediately after familiarization, their experience with the isolated words was still infant controlled, and as such not every infant got the same amount of experience with each of the target words. Thus, Experiment 4 was designed to replicate and extend the results of Experiment 2 with a more controlled experimental design. We hypothesized that as in Experiment 2, infants would show successful retention of HTP words when they hear isolated HTP and LTP words equally often. Furthermore, replicating the results of Experiment 2 would be important to show that these results are robust and may provide a stronger basis to make more definitive conclusions.

Eight-month-olds were given fixed amount of exposure to isolated target words immediately following familiarization with the Italian speech stream and were then tested on target words following a 10-minute delay. If they had attended only to isolated words, we would expect no difference in looking to each word type, since all target words would have an identical TP of 1.0. Thus, attention to the statistical properties of words during familiarization was required for infants to successfully discriminate HTP from LTP words.

Methods

Participants. Twenty-three healthy and full-term infants (12 males and 11 females) with a mean age of 8.3 months (range = 8 to 8.9) participated in Experiment 4. Infants were from monolingual English-speaking families and had no history of hearing or vision impairments, and no prior exposure to Italian or Spanish. Half of infants were randomly assigned to a counterbalanced language where LTP and HTP words switched.

Participants were recruited through the Child Development Research Group database maintained in the Department of Psychology at the University of Tennessee, Knoxville, and through community outreach initiatives in the greater Knoxville area. Seventeen additional infants were tested but not included in the analyses for the following reasons: fussiness (n = 11), not paying attention (n = 3), or experimental error (n = 7).

Stimuli. The auditory stimuli were the same as in the previous experiments. A video clip of a spinning pinwheel was used during both the familiarization and test.

Procedures. Experimental procedures were similar to those of Experiment 2. During familiarization, a video of spinning pinwheel was presented on the monitors contingent upon the infants' looking behavior, while one of the two counterbalanced languages played continuously from the side speakers. Immediately following familiarization, infants were given fixed experience with isolated target words (i.e., infants heard HTP and LTP words equally often in isolation). The two HTP word trials and two LTP word trials were presented three times, randomized by block (i.e., a total of 12 trials). On each trial a given target word was presented eight times in isolation, for a total of 24 exposures to each target word. Each fixed experience trial was initiated when infants looked to a video of a centrally-presented spinning pinwheel, at which point the experimenter signaled the center spinning pinwheel to extinguish and one of the side spinning pinwheel to begin playing. Once the infant had fixated on the side spinning pinwheel, an isolated token of HTP word or LTP word was presented eight times regardless of infants' subsequent looking preferences. As in previous experiments, side of stimulus presentation was counterbalanced.

Following the fixed experience phase, the infant played with the toys in the laboratory waiting room during a 10-minute delay. On returning to the testing room, infants were tested for their ability to differentiate HTP from LTP words.

Results and Discussion

We first compared the two counterbalanced languages. As there were no significant difference scores for the counterbalanced languages, t (21) = .89, p = .38, the two conditions were combined in the subsequent analysis. A paired sample t-test revealed a significant difference between looking times for HTP (M = 7.41 s, SE = .65) and LTP (M = 6.38s, SE = .53) words, t (22) = 2.9, p = .008, d = .6 (see Figure 1). Eighteen out of 23 infants looked longer to HTP words. Successful discrimination suggests that the use of isolated words seems to play a role in helping infants to successfully encode and remember the statistical properties of words after a delay.

Chapter 3

General Discussion

The literature on infant statistical language learning contains numerous studies suggesting that language learning is facilitated by the ability to track statistical regularities in linguistic input. Further, infants may be able to take advantage of the patterns they extract to support lexical development (Graf Estes, Evans, Alibaba, & Saffran, 2007; Hay et al., 2011). However, infant statistical learning has primarily been assessed in conditions that have limited ecological validity. For example, infant statistical learning has been typically assessed using testing procedures that are implemented immediately following familiarization with continuous speech. Testing infants' ability to extract words from continuous speech immediately after familiarization only tells us about what has been encoded. However, it does not tell us whether those words will be remembered over time.

A great deal of infants' speech input comes from overheard speech, where objects and concepts might not be in the infant's immediate environment (Akhtar, 2005; Akhtar, et al., 2001). Given the likelihood of a delays between the hearing speech from which candidate words are extracted and seeing the relevant referents in the environment, infants' ability to retain the statistical properties of words in memory are fundamental to lexical development. Infants may derive benefit from retaining statistical information over minutes, hours, or even days given the complex, real word environment in which language processing must occur outside of the laboratory environment.

The main goal of the present study was to explore the longevity of statistical learning in natural language input by assessing infants' long-term memory for statistically defined words. More specifically, the present study explored 8-month-old infants' ability to remember the sequential statistics of speech 10-minutes after familiarization with a naturally produced Italian corpus. In Experiment 1, English-learning 8-month-olds were familiarized with Italian sentences that contained four embedded target words. Following a 10-minute delay, discrimination of HTP from LTP words was tested using the Headturn Preference Procedure. The results of Experiment 1 showed that infants listened HTP and LTP words equally, suggesting that memory for statistical information may decay over even short delays. Statistical information might, therefore, be less available for later retrieval as time goes on.

Forgetting is one of the most pervasive features of human memory (Vlach & Sandhofer, 2012). Previous research has revealed that young infant and children's memory for newly learned words continuous to decay as time goes on (Horst & Samuelson, 2008; Vlach and Sandhofer, 2012). For example, Vlach and Sandhofer (2012) tested the young children's ability to map a novel word onto a novel object either over time (immediately, a 1-week delay, and a 1-month delay) and found that while children readily demonstrate knowledge of a newly learned object-label mapping when tested immediately, they forgot the object-label mapping over time. Horst and Samuelson (2008) found that whereas 2-year-old infants were good at mapping new words to novel referents when tested immediately using a at referent selection task, they did not retain the word-referent mappings over a 5-minute delay. In these studies, forgetting may result from a failure to encode or from ineffective encoding of details of the mapping into memory. Both the Vlach and Sandhoder (2012) and the Horst and Samuelson (2008) studies have also examined how encoding conditions influence long-term retention. Vlach and Sandhofer (2008) investigated whether providing additional memory supports (e.g., shaking the target object, repeating the label multiple times, and asking subject to produce the word for the target object) during learning would increase long-term retention of word mappings. They found that if infants were given additional memory support during learning, children remembered the novel words even after 1-month delay. Similarly, Horst and Samuelson (2008) showed that 2-year-old infants were able to retain words for 5 minutes when the referent selection task was augmented with ostensive naming. Together these studies indicate that providing additional support during learning may have prevented forgetting and facilitated retention by strengthening the encoding of the relevant words and by the words more salient.

Since successful encoding is a prerequisite for successful retrieval, infants must first robustly encode the statistical properties of words into memory. However, brief exposure to natural language corpora alone may not provide infants with sufficient experience with those properties to encode them into memory. Previous research suggests that hearing words in isolation facilitates statistical learning (Lew-Williams et al., 2011). Although infants' memory for the recently extracted statistically defined words are weak and likely to decay even over short delays, hearing those words in isolation immediately after familiarization may create stronger representations of statistical properties of words in memory. To this end Experiment 2 was designed to test the hypothesis that experience with isolated words immediately after familiarization with a fluent Italian speech selectively reinforces memory for statistically-defined sound sequences. To do so, 8-month-olds were familiarized with the same corpus and tested immediately following familiarization (T1), giving them experience with the words in isolation, and following a 10-minute delay (T2). Infants looked significantly longer to HTP words than LTP words after the 10-minute delay. Thus, when infants heard the statistically defined words both in continuous speech and in isolation, they successfully retain the statistical properties of words after the 10-minute delay.

It is noteworthy that when infants were tested immediately following familiarization, we failed to replicate the familiarity preference for HTP words seen in Pelucchi et al. (2009). Critically, however, listening preferences following the 10-minute delay were not correlated with listening preferences for isolated words immediately after familiarization, suggesting that individual differences in experience with the isolated words did not impact infants' preferences for HTP words at delayed testing phase. To explore whether methodological differences might have accounted for infants' failure to differentiate HTP from LTP words immediately after familiarization, in Experiment 3 a new group of 8-month-olds was familiarized with the same corpus while watching a more engaging visual stimulus (video of a spinning pinwheel) instead of video of a flashing light. Results showed that infants readily discriminated HTP from LTP words immediately after familiarization, suggesting that infants' performance at immediate testing in Experiment 2 may be due to sampling effects and minor methodological differences unrelated to the learning task or a Type 2 error. It might be the case that using more engaging visual stimuli improved infants' attention to the task which increases their attention to the auditory stimuli. There is also evidence that during the simultaneous presentation of auditory and visual information, attention is more likely to be directed to the auditory channel than the visual channel especially when the visual stimulus is complex (Bergen, Grimes, & Potter, 2005). More research will be needed to differentiate these alternatives.

There is some controversy among researchers studying early language acquisition about the role of isolated words in the input as a source information for word segmentation (e.g., Brent & Siskind, 2001; Lew-Williams, et al., 2011; Aslin, Woodward, LaMendola & Bever, 1996). For example, Aslin and colleagues (Aslin et al., 1996) argued that infant directed speech does not reliably provide isolated words. Since the seminal work of Saffran et al. (1996), there have been numerous demonstration that infants are equipped with remarkable statistical learning capabilities that may allow them to segment words from continuous speech. However, this may not be the only way that infants extract words from continuous speech. Previous work has also demonstrated that hearing words in isolation may help infants in word recognition by facilitating word segmentation (Fernald & Morikawa, 1993; Brent & Siskind, 2001; Fernald & Hurtado, 2006; Lew-Williams et al., 2011; Mersad & Nazzi, 2012). For example, Brent and Siskind (2001) analyzed parent – infant interactions and reported that approximately 9% of infant directed speech utterances consisted of isolated words. It is quite impressive that a child may hear up to 4 million isolated words by their forth birthday. Therefore, experience with isolated words may play an important role in early language acquisition by facilitating vocabulary development.

There is also some evidence suggesting that statistical speech segmentation can be bootstrapped by exposure to both continuous speech and isolated words. For example, recent work using naturalistic stimuli showed that the presence of both continuous speech and isolated words enhance infants' attention to statistical properties of words in fluent Italian speech (Lew-Williams et al., 2011). The successful encoding of statistical properties of words may require infants to integrate two sources of information: hearing statistically defined words both in speech stream and in isolation. Integrating information obtained from isolated words with statistical information available in continuous speech may also provide infants with a way to successfully store and eventually retrieve the statistical information from memory. In our study, isolated words could have functioned to make the task more difficult by reducing the TP between HTP (TP= 1.0) and LTP (TP= .33 → TP= .54) words. This, however, is not what we found. Instead, isolated words seem to be acting in concert with continuous speech. We suggest that experience with the isolated words may have led to a more complete encoding of statistical information and may thus have provided infants with a greater opportunity to retrieve the HTP words when tested later.

The degree to which infants are incorporating isolated words into their statistical computations and why isolated words selectively reinforced the HTP words are still unclear. However, we believe that hearing statistically defined words in isolation immediately after familiarization may have made the statistical properties of those words more readily encodable into memory and more accessible for later use. Much research is needed to shed light on the supporting role of isolated words in memory.

By systematically increasing the delay between familiarization and test, future research will also discover the limits of infants' long term memory for sequential statistics and thus the longevity of statistical learning across early language. However, other mechanisms (e.g. sleep) will also need to be considered when the retention interval is increased. Sleep and wakeful rest have been implicated in memory consolidation (e.g., Stickgold, 2005) and work by Gómez and colleagues (Gómez, Bootzin, & Nadel, 2006; Hupbach, Gómez, Bootzin, & Nadel, 2009) suggests that, for 15-month-olds, both a nap and overnight sleep promote the consolidation of newly learned simple non-adjacent dependency relations. Thus, it is plausible to assume that sleep can promote infants' memory for statistically defined words by allowing their brain to organize and consolidate memory traces. Additionally, future studies that examine over what delays a statistically-defined words can serve as the label of a referent object are also needed in order to demonstrate the viability of statistical learning as a mechanism driving natural language acquisition.

The strongest conclusion that can be drawn from these findings is that experience of hearing words in isolation immediately after familiarization appears to have selectively reinforced infants' long-term memory for high transitional probability words. The findings of the present study add significantly to the existing knowledge on infant statistical learning and provide initial support for the longevity of statistical learning in the first year. Memory for statistically defined words could bolster language acquisition by allowing those sound sequences to have a privileged status in new learning environments. Our findings are supporting the idea that infants have access to statistically defined sound sequences beyond the immediate familiarization context and demonstrating the feasibility of investigating infants' memory for words extracted from natural language input.

List of References

Akhtar, N. (2005). The robustness of learning through overhearing. *Developmental Science, 8*(2), 199- 209. PMid:15720377.

Akhtar, N., Jipson, J., & Callanan, M. (2001). Learning words through overhearing. *Child Development*, *72*, 416-430.

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1998). Computation of conditional probability statistics by 8-month-old infants. *Psychological science*, *9*(4), 321-324.

Aslin, R. N. & Newport, E. L. (2008). What statistical learning can and can't tell us about language acquisition. In J. Colombo, P. McCardle, and L. Freund (Eds.), *Infant pathways to language: Methods, models, and research directions.* Mahwah, NJ: Lawrence Erlbaum Associates.

Bäckman, L., Almkvist, O., Andersson, J., Nordberg, A., Winblad, B., Reineck, R., & Långström, B. (1997). Brain activation in young and older adults during implicit and explicit retrieval. *Cognitive Neuroscience, Journal of*, *9*(3), 378-391.

Bauer, P. J. (2002). Long-term recall memory: Behavioral and neuro-developmental changes in the first 2 years of life. *Current Directions in Psychological Science*, *11*, 137-141. Reprinted in *Annual Editions: Child Growth and Development, Tenth Edition* (2003), *Eleventh Edition* (2004), and *Twelfth Edition* (2005). Guilford, CT: McGraw-Hill/Dushkin.

Bauer, P. J. (2004). Getting explicit memory off the ground: Steps toward construction of a neuro-developmental account of changes in the first two years of life. *Developmental Review, 24*, 347-373.

Bauer, P. J. (2006). Constructing a past in infancy: A neuro-developmental account. *Trends in Cognitive Sciences*, *10*, 175-181. PMid:16537115.

Bauer, P. J. (2007). Recall in infancy: A neurodevelopmental account. *Current Directions in Psychological Science, 16*, 142-146. Reprinted in *Readings on the Development of Children* (2008). M. Gauvain & M. Cole (Eds.) New York, NY: Worth Publishers.

Benavides-Varela, S., & Mehler, J. (2015). Verbal Positional Memory in 7-Month-Olds. *Child development*, *86*(1), 209-223.

Bergen, L., Grimes, T., & Potter, D. (2005). How attention partitions itself during simultaneous message presentations. *Human Communication Research*, *31*(3), 311-336.

Bramham, C. R., & Messaoudi, E. (2005). BDNF function in adult synaptic plasticity: the synaptic consolidation hypothesis. *Progress in neurobiology*, *76*(2), 99-125.

Brent, M. R., & Siskind, J. M. (2001). The role of exposure to isolated words in early vocabulary development. *Cognition*, *81*(2), B33-B44.

Bergelson, E., & Swingley, D. (Feb. 2012). At 6 to 9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences of the USA, 109,* 3253-3258.

Clopath, C. (2012). Synaptic consolidation: an approach to long-term learning. *Cognitive neurodynamics*, *6*(3), 251-257.

Craig, M., Dewar, M., Della Sala, S., & Wolbers, T. (2015). Rest boosts the long-term retention of spatial associative and temporal order information. *Hippocampus*, *25*(9), 1017-1027.

Davis, M. H., Di Betta, A. M., Macdonald, M. J., & Gaskell, M. G. (2009). Learning and consolidation of novel spoken words. *Journal of Cognitive Neuroscience*, *21*(4), 803-820.

Dewar, M., Alber, J., Butler, C., Cowan, N., & Della Sala, S. (2012). Brief wakeful resting boosts new memories over the long term. *Psychological science*, 0956797612441220.

Dewar, M., Alber, J., Cowan, N., & Della Sala, S. (2014). Boosting long-term memory via wakeful rest: Intentional rehearsal is not necessary, consolidation is sufficient. *PloS one*, *9*(10), e109542.

Dudai, Y. (2004). The neurobiology of consolidations, or, how stable is the engram? *Annu. Rev. Psychol.* 55, 51–86.

Drummey, A. B., & Newcombe, N. (1995). Remembering versus Knowing the Past: Children′ s Explicit and Implicit Memories for Pictures. *Journal of Experimental Child Psychology*, *59*(3), 549-565.

Endress, A. D., & Hauser, M. D. (2010). Word segmentation with universal prosodic cues. *Cognitive psychology*, *61*(2), 177-199.

Ettlinger, M., Margulis, E. H., & Wong, P. C. (2011). Implicit memory in music and language. *The relationship between music and language*, 159.

Fernald, A., & Hurtado, N. (2006). Names in frames: Infants interpret words in sentence frames faster than words in isolation. *Developmental science*, *9*(3), F33-F40.

Fernald, A., & Morikawa, H. (1993). Common themes and cultural variations in Japanese and American mothers' speech to infants. *Child development*, *64*(3), 637-656.

Houston, D. M., & Jusczyk, P. W. (2003). Infants' long-term memory for the sound patterns of words and voices. *Journal of Experimental Psychology: Human Perception and Performance*, *29*(6), 1143.

Horst, J. S., & Samuelson, L. K. (2008). Fast mapping but poor retention by 24-month-old infants. *Infancy*, *13*(2), 128-157.

Gais, S., & Born, J. (2004). Declarative memory consolidation: mechanisms acting during human sleep. *Learning & Memory*, *11*(6), 679-685.

Gómez, R. L., Bootzin, R. R., & Nadel, L. (2006). Naps promote abstrac- tion in language-learning infants. *Psychol. Sci.* 17, 670–674.

Graf, P., & Birt, A. R. (1996). Explicit and implicit memory retrieval: Intentions and strategies. *Implicit memory and metacognition*, 25-44.

Graf, P., & Schacter, D. L. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *11*(3), 501.

Estes, K. G., Evans, J. L., Alibali, M. W., & Saffran, J. R. (2007). Can infants map meaning to newly segmented words? Statistical segmentation and word learning. *Psychological Science*, *18*(3), 254-260.

Gulya, M., Rovee-Collier, C., Galluccio, L., & Wilk, A. (1998). Memory processing of a serial list by young infants. *Psychological Science*, *9*(4), 303-307.

Hay, J. F., Pelucchi, B., Estes, K. G., & Saffran, J. R. (2011). Linking sounds to meanings: infant statistical learning in a natural language. *Cognitive psychology*, *63*(2), 93-106.

Hupbach, A., Gómez, R. L., Bootzin, R. R., & Nadel, L. (2009). Nap- dependent learning in infants. *Dev. Sci.* 12, 1007–1012.

Johnson, M. H., & De Haan, M. (2015). *Developmental cognitive neuroscience: An introduction*. John Wiley & Sons.

Jusczyk, P. W., & Hohne, E. A. (1997). Infants' memory for spoken words. *Science*, *277*(5334), 1984-1986.

Leonard, M. K., Bouchard, K. E., Tang, C., & Chang, E. F. (2015). Dynamic Encoding of Speech Sequence Probability in Human Temporal Cortex. *The Journal of Neuroscience, 35*(18), 7203-7214.

Leslie, A. M., & Keeble, S. (1987). Do six-month-old infants perceive causality?. *Cognition, 25*(3), 265-288.

Lew-Williams, C., Pelucchi, B., & Saffran, J. R. (2011). Isolated words enhance statistical language learning in infancy. *Developmental Science*, *14*(6), 1323-1329.

Mandel, D. R., Nelson, D. G. K., & Jusczyk, P. W. (1996). Infants remember the order of words in a spoken sentence. *Cognitive Development*, *11*(2), 181-196.

McNealy, K., Mazziotta, J. C., & Dapretto, M. (2006). Cracking the language code: Neural mechanisms underlying speech parsing. *The Journal of neuroscience*, *26*(29), 7629-7639.

Mersad, K., & Nazzi, T. (2012). When Mommy comes to the rescue of statistics: Infants combine top-down and bottom-up cues to segment speech. *Language Learning and Development*, *8*(3), 303-315.

Mestres-Missé, A., Càmara, E., Rodriguez-Fornells, A., Rotte, M., & Münte, T. F. (2008). Functional neuroanatomy of meaning acquisition from context. *Journal of Cognitive Neuroscience*, *20*(12), 2153-2166.

Nazzi, T., Bertoncini, J., & Mehler, J. (1998). Language discrimination by newborns: toward an understanding of the role of rhythm. *Journal of Experimental Psychology: Human perception and performance*, *24*(3), 756.

Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science*, *349*(6251), aac4716.

Pelucchi, B., Hay, J. F., & Saffran, J. R. (2009). Statistical Learning in a Natural Language by 8-Month-Old Infants. *Child development, 80*(3), 674-685.

Pelucchi, B., Hay, J. F., & Saffran, J. R. (2009). Learning in reverse: Eight-month-old infants track backward transitional probabilities. *Cognition, 113*(2), 244-247.

Rovee-Collier, C. (1997). Dissociations in infant memory: rethinking the development of implicit and explicit memory. *Psychological review*, *104*(3), 467.

Rovee-Collier, C. (1999). The development of infant memory. *Current Directions in Psychological Science*, *8*(3), 80-85.

Rovee-Collier, C., & Cuevas, K. (2009). Multiple memory systems are unnecessary to account for infant memory development: an ecological model. *Developmental psychology*, *45*(1), 160.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*, *274*(5294), 1926-1928.

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27-52.

Stickgold, R. (2005). Sleep-dependent memory consolidation. *Nature* 437, 1272–1278.

Stickgold, R., & Walker, M. (2005). Memory consolidation and reconsolidation: What is the role of sleep. Trends in Neurosciences, 28, 408–415.

Straube, B. (2012). An overview of the neuro-cognitive processes involved in the encoding, consolidation, and retrieval of true and false memories. *Behavioral and Brain Functions*, *8*(1), 1.

Thiessen, E. D., & Saffran, J. R. (2003). When cues collide: use of stress and statistical cues to word boundaries by 7-to 9-month-old infants. *Developmental psychology*, *39*(4), 706.

Von Restorff, H. (1933). Über die wirkung von bereichsbildungen im spurenfeld. *Psychologische Forschung*, *18*(1), 299-342.

Vlach, H. A., & Sandhofer, C. M. (2012). Fast mapping across time: Memory processes support children's retention of learned words. *Frontiers in psychology*, *3*(4).

Winocur, G., Moscovitch, M., & Bontempi, B. (2010). Memory formation and long-term retention in humans and animals: Convergence towards a transformation account of hippocampal–neocortical interactions. *Neuropsychologia*, *48*(8), 2339-2356.

Wojcik, E. H. (2013). Remembering new words: integrating early memory development into word learning. *Frontiers in psychology*, *4*.

Appendix

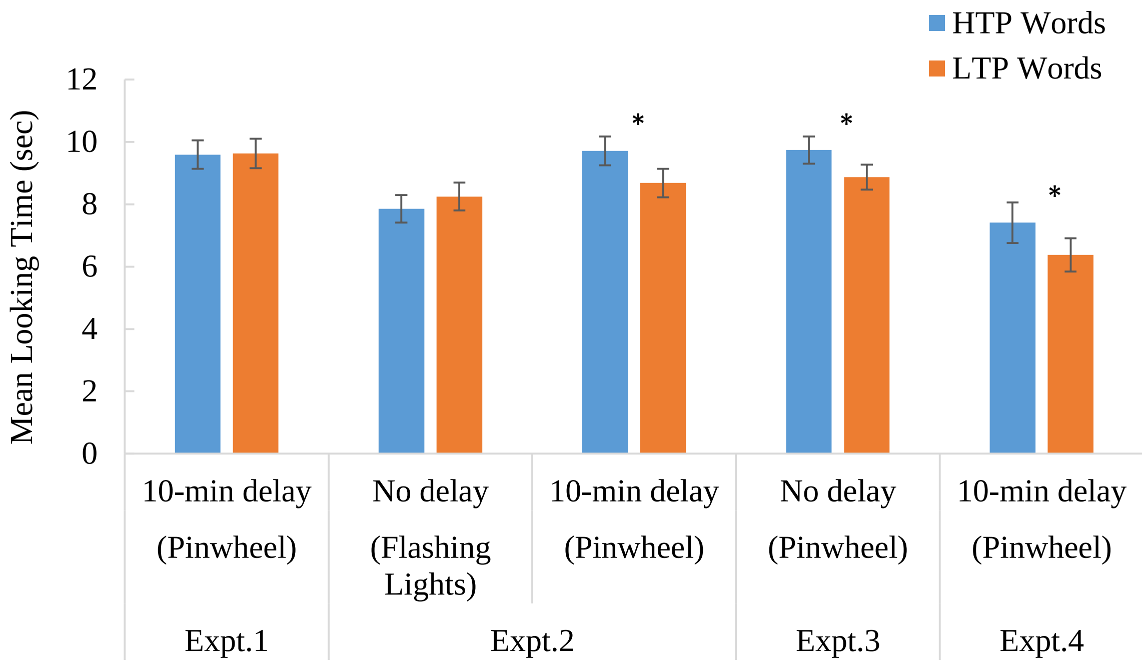

Figure 1. Mean looking time (sec) to HTP and LTP words following familiarization in Experiment 1 (testing following 10-minute delay), Experiment 2 (infant-controlled experience with isolated words at T1 + testing following 10-minute delay), Experiment 3 (immediate testing with pinwheel) and Experiment 4 (a fixed amount of experience with isolated words + testing following a 10-minute delay).

Language A

HTP words: *fuga, melo* LTP words: *casa, bici*

Torno a casa con le bici cariche di frutta in bilico sulla sella.
La zia Carola si e` esibita in una fuga colla bici verde.
Se porti il melo sulla bici forse cali un po' di chili.
La bici ha subito un danno dentro la casa del capo di Lara.
La cavia Bida e` in fuga da casa per aver giocato con le bilie blu.
La biscia in lenta fuga dal giardino capita in casa mia.
Il tuo melo arcano fuga l'afa che debilita la folla.
Arriviamo in bici fino al bivio del grande melo con un caro amico.
Il picchio si abitua a fare la sua casa in ogni melo cavo e alto.
Gusto i bigoli dentro casa o coricata all'ombra del melo verde.
Di rado una bici in rapida fuga rincorre la moto bigia e rossa.
Per ascoltare la fuga quasi cadi sul melo e inciampi sulla biro sull'erba.

Language B

HTP words: *casa, bici* LTP words: *fuga, melo*

Non e` da me scendere dal melo in una futile fuga dalle api.
Torno a casa dalla futa con la bici piena di mele mature.
Il melo e diverse bici furono portate presso la mescita di vino.
Zio Luigi Medo e` in fuga colla bici verde.
Vi fu l'eta` dei tentativi di fuga in bici verso il rifugio del melo antico.
Il fu Romero Rossi temeva di andare in gita colla bici nuova.
Dario fu l'ingenuo che porto` una bici a casa il mese scorso.
Una fuga da casa e` il sogno della topina Mela verso la liberta`.
Il ratto Meco tento` la fuga da casa quando vi fu la tempesta.
Il micio Refuso medita in casa o dimena la coda sotto al melo ombroso.
Sui rami del melo che sembrano fusi c'e` la casa del fuco solitario.
La fuga della stella cometa si e` fermata sul melo che fu della zia

Vita

Ferhat is currently a third year doctoral student in Experimental Psychology at the University of Tennessee, Knoxville, working under the supervision of Dr. Jessica F. Hay. Prior to attending to UT, he received his BA degree in Counseling Psychology from Sakarya University in Turkey in 2009 and his MA degree in Experimental Psychology from Florida Atlantic University in 2013. His general research interests are in the cognitive mechanisms that underlie language acquisition and memory processes in infancy. His research in the Infant Language and Perceptual Learning Lab focuses on how infants encode the sound patterns of words into long-term memory and remember them over time. He is also interested in the acquisition of vowel harmony in Turkish and infants' sensitivity to vowel harmony patterns.