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On-line lexical competition during spoken word recognition and word learning in children and adults

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Abstract

As speech input is processed multiple candidate words are automatically activated and compete for selection, a process referred to as lexical competition. Two experiments used pause detection to examine whether incremental lexical competition operates early in children's speech perception (as the speech string unfolds), as it does in adulthood. In Experiment 1 children and adults were slower to detect pauses inserted in familiar words with late uniqueness points (LUPs), compared with early uniqueness point (EUP) words, for both isolated words and within sentence contexts. Furthermore, faster pause detection latencies were obtained for LUP words presented in constraining compared to neutral sentences but there was no such context effect for EUP words, suggesting that lexical competition is contextually modulated on-line in children and adults. In Experiment 2 children and adults were exposed to novel competitors ("biscal") of existing words ("biscuit") with early uniqueness points. We examined whether the onset of lexical competition between novel and existing words could be used as an indicator of 'lexicalisation' across development. In both groups, lexical competition was observed for existing words but only after a period of consolidation. These findings suggest that early, incremental lexical competition effects during spoken word recognition are remarkably similar in children and adults and can be modulated on-line by both sentential context and the introduction of a novel competitor.

Keywords: Lexical access, lexical-contextual integration, vocabulary acquisition, complementary learning systems, sentence processing

Healthy adults can process their native language with remarkable efficiency, comprehending 120-200 words per minute in everyday speech (Crystal & House, 1990). Listeners typically use phonetic information immediately as it becomes available and can identify words long before they end (Marslen-Wilson, 1987). One phenomenon crucial to rapid incremental speech processing is lexical competition, defined as multiple lexical candidates, each activated in parallel in accordance to their similarity to the unfolding speech signal, competing for recognition. The process of incremental lexical competition has been emphasised by many models of word recognition (Gaskell & Marslen-Wilson, 2002; Grainger & Jacobs, 1996; Luce & Pisoni, 1998; Marslen-Wilson, 1989; McClelland & Elman, 1986; Norris, 1994). According to the Cohort model (Marslen-Wilson & Zwitserlood, 1989) lexical competition occurs 'on-line' between phonologically similar words up to the uniqueness point: the point at which only one word in the lexicon matches the speech input (but cf. Luce & Pisoni, 1998). Although there is considerable evidence for on-line lexical competition in adults (Gaskell & Dumay, 2003; Mattys & Clark, 2002) it remains unclear whether this phenomenon characterises the developing lexicon in the same way. There is some evidence for lexical competition effects in children from paradigms that measure lexical competition at the end point of word recognition (Garlock, Walley & Metsala, 2001; Metsala, 1997; Metsala et al., 2009; Munson, Swenson & Manthei, 2005; Sekerina & Brooks, 2007; Walley, 1993); however evidence is lacking from on-line paradigms that measure incremental lexical activity *early* in processing prior to a word's completion. Hence, it remains possible that the lexical competition effects that have been measured in children reflect offline identification rather than a continually updated competition process based initially on partial information. The initial aim of this study was to determine the properties and extent of *early* lexical competition in the developing lexicon during spoken word recognition by using the on-line pause detection paradigm for the first time in children. Further to this, our aim was to examine how any early competition effects can be modulated by two key parameters that have shown to be influential in adult studies. We looked at whether on-line competition can be influenced by the semantic fit between lexical candidates and their preceding sentential context. Furthermore, we examined the change in competition caused by the acquisition of a novel competitor, both soon after learning and after a consolidation period of a day. In combination, these manipulations provide a thorough examination of the nature of lexical competition in children, promoting a deeper understanding of the mechanisms underlying both spoken word recognition and acquisition across development.

Lexical competition in the developing lexicon: Single word recognition

Preferential looking studies suggest that by 2 years of age children process words in an incremental fashion (Fernald, Pinto, Swingley, Weinberg & McRoberts, 1998; Swingley, Pinto & Fernald, 1999). However, evidence from neurophysiological techniques that examine processing with greater temporal resolution suggests that spoken-word recognition does not reach adult-like levels until after age 7. Ojima, Matsuba-Kurita, Nakamura and Hagiwara (2011) presented children with picture contexts that either matched or mismatched spoken words and measured event related potentials. They reported that the onset of the N200 to the spoken words (argued to reflect phonological mismatch) decreased by approximately 70 ms between 7 and 9 years of age but remained stable between 9 and 11 years. This suggests that the speed (or automaticity) with which spoken words are processed continues to develop until at least 9 years of age.

Studies have examined lexical competition across development using a range of behavioural paradigms such as lexical decision, nonword repetition and gating. Findings from such studies converge on the view that the strength of lexical competition effects increases depending on both chronological age and the age at which the stimuli have been acquired (Garlock et al, 2001; Metsala, 1997; Metsala et al., 2009; Munson et al., 2005; Sekerina & Brooks, 2007; Walley, 1993). Indeed, lexical competition is the result of having lexical items that can compete, which develops as individuals acquire more and more lexical items. Using a nonword repetition task Munson et al (2005) found that 7-year-olds demonstrated phonological facilitation (faster responses for nonwords with higher phonotactic probability) and lexical competition (slower responses for words with higher neighbourhood density) whereas 4-year-olds showed no difference in repetition latencies as a function of phonotactic probability or neighbourhood density. Metsala et al. (2009) also reported that 7- and 9-year-olds showed an inhibitory effect of neighbourhood density in a repetition task but this effect was limited to highly familiar and early acquired words in a gating task (see also Imai, Walley & Flege, 2005, for similar findings in adult second language learners). These findings suggest that lexical competition may be more difficult to detect in younger children as a result of them knowing fewer words and having less dense lexical neighbourhoods.

According to the ‘lexical restructuring’ hypothesis word recognition is accomplished via more holistic than segmental processes early in language acquisition and as vocabulary grows lexical representations become more fine-grained as the need to distinguish between similar-sounding items increases (Charles-Luce & Luce, 1995; Dollaghan, 1994; Fowler, 1991; Jusczyk, 1993; Metsala & Walley, 1998; Metsala, 1997; Nittrouer, 1996; Walley, 1993; Ziegler & Goswami, 2005). This has also been demonstrated in adults by Magnuson, Tanenhaus, Aslin and Dahan (2003) who used an artificial lexicon paradigm and found the same progression from ‘holistic’ to ‘segmental’ competition as adults learned new words.

Furthermore, at 7 and 8 years, phonological (Storkel & Rogers, 2000) and orthographic (Castles, Davis, Cavalot & Forster, 2007) representations are more loosely specified than in adulthood. If word recognition is indeed more holistic or based on less richly specified representations it is feasible that earlier in development lexical competition between co-activated representations will tend to occur only after a delay, following completion of a word stimulus, particularly for recently acquired words. By this view, as development proceeds the lexical competition process will become more on-line and more incremental, leading to better use of partial information during the course of a word's perception.

The tasks used to measure lexical competition in previous developmental studies arguably have a number of caveats that limit the scope of the conclusions drawn. In contrast to naturalistic speech processing, gating tasks require explicit awareness of potential lexical candidates, which may dilute competition effects, particularly for less familiar words. Competition effects observed in repetition tasks might reflect interference during speech production in addition to or instead of heightened lexical activity early in the recognition process. Most critically however, none of the tools previously used in developmental studies provide a truly on-line indicator of incremental lexical competition as the speech string unfolds. To measure early lexical competition response measures must be sensitive to the time course of processing as a spoken word unfolds and must allow the experimenter to monitor lexical activity in continuous speech. Depending on the paradigm used, the observed competition effect might reflect lexical activity that occurs very early in spoken word processing or the effect might occur only after perceptual information has accumulated (i.e., at the end of a word). This is an important issue since it is possible that the mechanisms that underlie lexical competition may differ across development. As outlined above, lexical competition may occur later in speech processing in children (i.e., at the point of recognition) if indeed they have less well specified lexical representations or slower word processing speed than adults (Ojima et al., 2011).

One possible solution to these methodological limitations is to use the pause detection paradigm, which in our view holds many advantages over lexical decision, repetition and gating tasks but has not yet been used in children. Mattys and Clark (2002) introduced this technique, showing that the speed with which listeners detect silent pauses in words provides an on-line indicator of lexical activity in adults. When a short pause (denoted as "_") is inserted into a word with few or no possible completions (e.g., "bisc_uit") it is detected faster than when the word has more than one completion (e.g., "cabb_age/in/inet"). Similarly, pause detection latencies are faster for words with early uniqueness points (e.g., "tul_ip") compared with words with later uniqueness points (e.g., "conc_ern"). Pause detection latencies are argued to be influenced by both processing resource availability and violation of lexical expectancy (Mattys & Clark, 2002): Latencies will be faster if lexical activity has stabilized to a single candidate when the pause is encountered because more resources are available for pause detection. The task provides an index of lexical activity that is indicative of lexical activity at a given point in a speech string rather than at the end-point of recognition. Moreover, it does not require explicit judgement about the linguistic content as many other tasks do and hence reduces the likelihood of strategic processing. This is particularly important in the context of testing children who are likely to have less metalinguistic awareness of the linguistic status of stimuli (Chaney, 1992; Edwards & Kirkpatrick, 1999). Hence, the first aim of the present study is to use the pause detection paradigm to determine whether children show lexical competition effects prior to stimulus completion, indicative of adult-like incremental lexical processing.

Lexical competition in the developing lexicon: Sentence processing

When adults process connected speech, competition is thought to depend not only on lexical factors but also on their interaction with semantic/contextual information (Connine & Clifton, 1987; Grosjean, 1980; McAllister, 1988; Samuel, 1981; Tyler & Wessels, 1983; Zwitserlood, 1989). Interactionist models of lexical-contextual integration propose that lexical and semantic processes are heavily interactive and their integration occurs early and rapidly during spoken word recognition (McClelland, 1987; Tabossi, 1988; Van Petten & Kutas, 1987). The opposing modular stance assumes that initial lexical activity occurs without any influence of sentence context early in processing, but is followed by a contextual integration process which allows the appropriate meaning of a word to be selected (Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Leiman & Bienkowski, 1982, Swinney, 1979). Evidence from adults largely supports the interactionist account. For instance, using pause detection, Mattys, Pleydell-Pearce, Melhorn and Whitecross (2005) asked participants to detect 200ms pauses in sentence-final words. For words with early uniqueness points, constraining versus neutral sentence context had little influence on pause detection latency. However, for words with later uniqueness points, constraining context decreased pause detection latencies relative to neutral context. This suggests that the point at which a word is identified can be brought forward in time if the preceding sentence context increases its likelihood and that context exerts an influence on lexical processing even as the speech sequence is unfolding.

It is unclear whether children's contextual processing is fast enough for it to impose strong constraints on lexical activity. Studies examining lexical ambiguity resolution have provided rather mixed evidence. In the visual modality, Booth, Harasaki and Burman (2006) reported that 12-year-olds (but not 9-10-year-olds) showed facilitation from biased versus neutral written sentence context when naming subsequent target words that were presented 1000 ms after sentence offset. This suggests that younger children may show more modular lexical-contextual integration even 1000 ms after the sentence has been processed (although see Simpson et al., 1994).

In the auditory modality, Khanna and Boland (2010) presented 7-10-year-olds and adults with spoken sentences containing ambiguous homonyms (e.g., bank). Immediately at homonym offset participants were presented with a target word for naming. The sentences were congruently related to the target word, incongruently related through the alternative meaning, neutral (i.e., not biased towards either meaning) or unrelated. Younger children aged 7-9-years were faster to name target words that were preceded by congruently related and incongruently related sentences compared with unrelated sentences whereas 9-10-year-olds and adults only showed facilitation for the congruently related sentences. Thus, immediately after processing the sentence, the 7-9-year-olds showed more modular lexical-contextual processing and were less sensitive to sentence context (supporting Booth et al., 2006). However, also presenting spoken sentences but using a slightly longer ISI between sentence offset and target onset Henderson, Clarke and Snowling (2011) provided evidence that lexical activity does interact with sentence context. They presented 8-year-old children with spoken sentences that ended in homonyms and were biased towards the subordinate meaning (e.g., “John fished from the bank”) or neutral control sentences. 250 ms after homonym offset, children named picture targets that were subordinate (context-appropriate e.g., river) or dominant (context-inappropriate e.g., money) associates of the homonyms. Children were faster to name subordinate pictures when they were preceded by subordinate than control sentences but did not show facilitation for dominant pictures when they were preceded by subordinate sentences. This suggests that from 8 years of age, preceding sentence context interacts with lexical activity to facilitate relevant meanings and suppress irrelevant meanings from at least 250 ms after picture onset. However, the sentence priming paradigm cannot determine the extent to which lexical activity is influenced by context as the critical word is being processed. Thus, none of these studies have examined issues of interactivity versus autonomy during early stages of word recognition.

Arguably, children's lexical systems may be just as interactive as adults but their slower processing speeds may make this interactivity harder to detect, particularly in tasks such as sentence priming which arguably carries greater executive and metalinguistic demands than naturalistic speech processing. This again motivates the use of pause detection as a more on-line measure of lexical-contextual processing in children.

Lexical competition during novel word learning

Another key area in which measures of lexical competition have proved fruitful in adult research is spoken word acquisition. To fully acquire a new spoken word it must be integrated into the lexicon and compete with similar-sounding linguistic representations (Davis, Di Betta, MacDonald & Gaskell, 2009; Leach & Samuel, 2007). Lexical competition can therefore provide an indicator of when a novel word has been 'lexicalised' and begins to possess the hallmarks of an existing lexical representation. However, it is currently unclear whether lexical competition can be used as a marker of word learning in children as it can in adults, since we lack the vital evidence that children show the same *early* lexical competition effects as adults when measured with on-line paradigms.

Evidence of early lexical competition between existing words and novel competitors would provide perhaps the clearest support for the influence of lexical parameters such as UP on word identification in children. As anticipated by Cutler (1981) it is becoming increasingly difficult to match stimuli lists for relevant characteristics such as age of acquisition, imageability, familiarity and morphological complexity. Bowers, Davis and

Hanley (2005) argued that “researchers are far from characterising all the variables that influence word identification, and thus any attempt to match items across conditions is problematic” (p. B46). Therefore, any comparison of different sets of LUP and EUP words is bound to be subject to some uncertainty. One solution to this problem, adopted by Bowers et al, and also used here, is to take a set of existing words with early uniqueness points (e.g., biscuit) and to manipulate the presence of a lexical competitor by introducing novel words (e.g., biscal) into participants’ lexicons.

Such an approach was also taken by Gaskell and Dumay (2003) who reported that pause detection latencies in early-unique words such as “cathe_dral” become slower if adults have recently learned an onset competitor “cathedruke”. Research suggests that sleep plays an important role in the emergence of lexical competition between novel nonwords and their existing competitors (Tamminen et al., 2010). Dumay and Gaskell (2007) showed that lexical competition emerged 12 hours after exposure to the novel word competitors, but only if that 12 hour period included sleep. Sleep also benefited free recall of the novel nonwords suggesting that off-line consolidation not only aids the integration of novel words into the lexicon, but may also play a role in the stabilization and/or enhancement of new phonological representations. Gaskell and colleagues (Davis & Gaskell, 2009) have interpreted these results within the *complementary learning systems (CLS)* framework (McClelland, McNaughton, & O’Reilly, 1995; Norman & O’Reilly, 2003; O’Reilly & Norman, 2002; O’Reilly & Rudy, 2001) whereby new information is initially stored separately from existing knowledge and then integrated over time. Evidence suggests that new information about novel words is initially sparsely coded in the hippocampus but that offline replay of these representations results in strengthening of representations in long-term neocortical memory where they are stored as overlapping distributed representations (Davis et al., 2009; French, 1999; Robins & McCallum, 1999; Wilson & McNaughton, 1994).

In support of the idea that the representations of novel phonological forms strengthen after a period of consolidation, recognition of novel words has been shown to improve one week after initial training in 3-6 year old children (Storkel, 2001; Storkel & Lee, 2011) and up to 24 weeks later in 6-7 year olds (Dockrell, Braisby, & Best, 2007) without any additional exposure. However, there is a lack of research to suggest that an increase in lexical competition between novel words and existing competitors also occurs after a period of off-line consolidation across development.

A previous study carried out in our lab (Brown, Weighall, Henderson & Gaskell, in press) examined short-term and longer-term changes in explicit memory representations for novel words in children. Brown et al. (in press) trained novel nonwords ("brambooce") to children aged 6-8 and 11-13 years and tested them on recognition and recall of these nonwords immediately and after 6 or 24-hours. The key finding was that both age groups showed clear improvements in recall after 24-hours (supporting previous studies and the role of off-line consolidation in word learning across development). In a first attempt to measure changes in lexical competition after off-line consolidation, children also made lexical decisions to similar sounding existing words ("bramble") and control words. However, weak and unreliable lexical competition effects were evident both immediately and 24-hours after training. A tentative explanation of these data could be that children do not need a consolidation period before novel words are integrated into the lexical competition process. Since children have smaller vocabularies they may be able to integrate new words with their neighbours faster than adults, without the risk of overwriting existing information (O'Reilly, 2006). However, this explanation is problematic since there was substantial variability in the lexical competition effects obtained, particularly for the younger group. Further, the finding of competition immediately after exposure contradicts previous findings that lexical competition effects for familiar words are present in children but only for early acquired words (Garlock et al., 2001; Munson et al., 2005). Therefore, it remains unclear whether the time-course of lexical integration of a novel nonword is the same in children as in adults or whether new words engage in lexical competition immediately after learning. Critically, as outlined above, it also remains unclear whether children show incremental lexical competition effects similar to adults when on-line paradigms are used and therefore whether lexical competition is a suitable indicator of lexical integration.

To address these shortcomings, the present study builds on Brown et al. using the pause detection paradigm to first determine whether children show on-line lexical competition effects for known words before examining whether such competition emerges for novel words after a period of off-line consolidation, as in adults. Pause detection may show greater sensitivity to lexical competition in children than lexical decision, which has higher executive demands, relies on explicit lexical knowledge, and cannot measure lexical activity as words are being processed. Moret-Tatay and Perea (2011) reported that the yes/no lexical decision task (as used in Brown et al) produces slower responses, more errors, and more error variance than the go/no-go lexical decision task when used in 7-10-year-olds. Moreover, examining the emergence of incremental lexical competition during nonword learning has a number of important theoretical benefits. Namely, in addition to examining the influence of sentence context on lexical competition, this experiment provides a further demonstration of whether early competition effects can be modulated by a key parameter shown to be influential in adult studies, and the use of novel nonword stimuli provides a solution to the potential confounds of stimulus matching in UP experiments. Furthermore, we provide novel information on consolidation processes during word learning in children.

The present study

We used pause detection to address three interrelated research questions: (1) Do children show incremental lexical competition effects when identifying pauses in words with late versus early uniqueness points and are these effects comparable to adults? (2) Can early lexical activity be modulated on-line by semantic context in children as in adults when an on-line paradigm is used? More specifically, do children show context effects for words with late but not early uniqueness points (as shown by Mattys et al., 2005, in adults)? (3) Can lexical competition be used as an indicator of lexical integration of novel nonwords in children as in adults and is the time-course of lexical integration of novel nonwords the same in children as in adults? Answering these questions will address whether children show the hallmarks of adult language processing when an on-line paradigm is used, specifically focusing on early incremental lexical competition. Questions (1) and (2) are important in determining whether automatic lexical competition characterises the developing lexicon as it does in adulthood. Question (3) goes a step further in examining whether automatic lexical competition can be used as an index of 'lexicalisation' in children (the process of a novel word becoming part of the lexicon). Furthermore, in addressing questions (2) and (3) we aimed to establish whether lexical activity is flexible in children, namely, whether lexical activity can be altered by context and by the introduction of a novel competitor. Children aged 7 – 8 years were the focus of this study because their lexical processing does not yet appear to be fully adult-like (Ojima et al., 2011) and vocabulary learning remains crucial and well-practised.

Experiment 1

Experiment 1 addressed the first two research questions and examined lexical competition in children and adults in single-word and sentence contexts. For both single-word and sentence processing, it was predicted that pause detection latency would be faster for existing/known words with early uniqueness points (EUPs) than words with late uniqueness points (LUPs) but that the size of this lexical competition effect would be smaller in children than in adults. Based on previous findings that children with smaller vocabularies exhibit weaker competition from small phonological units (Storkel & Hoover, 2011; Storkel & Lee, 2011) we also hypothesised that the magnitude of competition in children would be positively correlated with lexicon size (receptive vocabulary). Based on Mattys et al (2005), we predicted that adults would show faster pause detection latency for LUP words when those words are embedded in constraining sentence context (relative to a neutral context condition) whereas there should be no effect of context for EUP words. Given the disparity in the developmental literature, no clear hypotheses were possible for the Context x UP interaction in children.

Method

Participants

Twenty children (10 males) aged 7–8 years old and 17 adults (5 males) aged 18–23 years old participated. Children were recruited from mainstream primary schools; adults were undergraduate students from the University of York. Participants were native English speakers, had no reported learning disabilities, and had normal/corrected-to-normal vision and hearing. Informed parental consent was obtained for children; adults provided written consent. Both groups showed a normal range of scores on standardized measures of receptive vocabulary (the Peabody Picture Vocabulary Test 4th Edition; Dunn & Dunn, 2007) and phoneme awareness (the Phoneme Elision subtest from the Comprehensive Test of Phonological Processing (Torgesen, 1999) (Table 1).

Stimuli

All stimuli were recorded on a Pioneer PDR 509 system by a female native English speaker. Following Gaskell and Dumay (2003), 200 ms pauses were inserted immediately before the final vowel for two syllable words and immediately before final syllable for three syllable words. For both single-word and sentence tasks the proportion of items containing pauses was 60% (Mattys & Clark, 2002; Mattys et al., 2005).

Single-word task

Fifty-two bisyllable and trisyllable words were used: 26 had LUPs, with at least two possible continuations at the end of their initial fragment (e.g., *cabbage*, where the fragment *cab* is consistent with *cabbage*, *cabin* and *cabinet*), and 26 had EUPs and were uniquely identifiable at the end of their initial fragment (e.g., *brek* is unique to *breakfast*). The mean uniqueness point of the LUP words was significantly later than for the EUP words (t=7.07, p<.001) (as estimated using the Celex database, Baayen, Piepenbrock, & Gulikers, 1995). LUP and EUP lists were matched on their recorded length including the pause, letter length, syllable length, phonological neighbours, familiarity (using the MRC Psycholinguistic Database, Version, 2.00, Wilson, 1988), and frequency (Children's Printed Word Database (www.essex.ac.uk/psychology/cpwd)). Stimuli were rated for AOA by 21 adults (11 males; mean 21.42 years, SD = 7.08 years) with no significant difference between EUP (mean 5.85 years, SD=1.10 years) and LUP (mean 6.06 years, SD=1.21 years) conditions (p>.05). Fifty-two filler words were included that did not contain a pause and a further 26 filler words contained pauses in earlier positions. Fillers were matched to experimental stimuli on letter length, frequency and initial letter.

Children also completed a lexical decision task to measure their familiarity with the late-diverging competitors of the 26 LUP words (e.g., *cabinet* and *cabin* for *cabbage*). The competitors (n=58) were presented via headphones using DMDX (Forster & Forster, 2003) in addition to an equal number of phonetically plausible nonsense words. The percentage of children that responded 'word' to each competitor was calculated and LUP items with <75% accuracy were removed from statistical analyses of lexical competition for both groups. Items in the EUP list (matched on phoneme length and frequency) were also removed to maintain equal item numbers in each condition. Following this procedure, 18 items remained in each of the LUP and EUP conditions. A control experiment was carried out to rule out that any observed difference in EUP and LUP conditions could be due to differences in acoustic rather than lexical properties of the stimuli[1]. Appendices A and B show the stimuli used and their properties, respectively.

Sentence task

The 26 LUP words and 26 EUP words were used as sentence-final words in two conditions: The constraining condition provided a semantically constraining context for the word whereas the neutral condition provided a non-constraining context (Appendix C). Constraining and neutral sentences were matched for syntactic structure, number of words and acoustic duration. Fillers comprised 104 sentences that contained no pauses and 52 sentences that contained earlier pauses at a range of positions within the sentences. Half of the fillers were constraining; the others ended with the same words but were neutral.

A sentence-completion task was administered to the same participants who provided AOA ratings (the sentence-completion task was administered first). Participants read the sentences in a randomised order but with the final words omitted. For the LUP condition, cloze probability (the proportion of correct guesses for the final word) was higher in the constraining than neutral condition (constraining mean=.30, SD=.26; neutral mean=.003, SD=.01; *p*<.01) and when closely related guesses were included (e.g. *alley* for *passage*) (constraining mean=.85, SD=.17; neutral mean=.003, SD=.01; *p*<.001). For the EUP condition, cloze probability was higher for constraining than neutral conditions (constraining mean=.50, SD=.38; neutral mean=.01, SD=.05), *p*<.001, and when closely related guesses were included (constraining mean=.80, SD=.17; neutral mean=.04, SD=.09; *p*<.001).

Design

Participants heard all items in all conditions. All participants attended three experimental sessions on different days (approximately one week apart). The first session comprised the single-word task. The stimulus list was split into two blocks separated by a five minute break. Each block contained half of the EUP and LUP words, half of the fillers without pauses and half of the fillers with earlier pauses. The sentence task was administered in the second and third sessions so that a word only occurred once in each session (half in the constraining and half in the neutral condition) with the order counterbalanced across participants. All experimental tasks in this paper were run on a Toshiba Satellite laptop computer and delivered via headphones using DMDX (Forster & Forster, 2003). Responses were collected using an 850F Vibraforce Feedback Sightfighter game-pad. The blocks and the items within them were pseudo-randomised.

Procedure

Children were tested individually in a quiet room in school; adults were tested individually in a University laboratory. The single-word task was administered in Session 1. Each trial began with a central fixation cross for 2000ms. The word was then played through headphones at a comfortable listening level and simultaneously a green circle containing the word ‘Pause’ and a red circle containing the word ‘No Pause’ appeared on the screen.

Participants were instructed to listen carefully to each word and press the green button on the game-pad if they heard a short silent pause in the word and to press the red button if they did not. Participants were instructed to respond as quickly and carefully as possible. Six practice items were administered (three with pauses) with corrective feedback. No feedback was given for experimental items. Accuracy and RT (from pause onset) were recorded. After the single-word pause detection task, children completed standardised measures of receptive vocabulary and phoneme awareness, and the lexical decision task. The sentence task was administered in the same way in Sessions 2 and 3 with the exception that children were instructed to listen carefully to each sentence instead of each word.

At the end of the experiment, children completed a picture-word matching task to measure their familiarity with the words. Each experimental item was depicted as a picture and presented with three distracters in a quadrant. The location of the target picture was pseudo-randomised. Children were unable to correctly identify the matching picture for a mean of 0.80 items (out of 18) in the LUP condition (SD=0.83) and 0.40 items (out of 18) in the EUP condition (SD=0.11), $p>.05$. Unfamiliar items on this task were removed from statistical analysis participant-by-participant.

Results

RTs were analysed for correct responses. Extreme RTs (<200ms and >2.5 SDs from the condition mean) were removed: Single-word task, Adults, LUP=1.70% (SD=3.12%), EUP=3.78% (SD=3.67%), Children, LUP=2.86% (SD=3.59%), EUP=2.14% (SD=3.36%); Sentence task, Adults, LUP=1.74% (SD=0.69%), EUP =1.31% (SD=1.99%), Children, LUP=0.82% (SD=1.30%), EUP=1.47% (SD=1.73%).

Single-word Processing

Mixed-design ANOVAs were performed by-participants (F_1) and by-items (F_2) with UP (LUP, EUP) as the within-subjects factor and Age (adult, child) as the between-subjects factor. Throughout this paper, main effects and interactions will only be reported if significant.

RT

Children were slower to respond than adults (Age, $F_1(1, 35)=17.60$, $p<.001$, $\eta_p^2=.34$, $F_2(1, 34)=203.07$, $p<.001$, $\eta_p^2=.86$), and slower responses were shown for the LUP than EUP condition (UP, $F_1(1, 19)=13.28$, $p<.01$, $\eta_p^2=.28$, $F_2(1, 34)=14.41$, $p<.01$, $\eta_p^2=.30$). Lexical competition (LUP RT – EUP RT) was observed for children (mean difference 117ms, SD=194ms, $p<.05$) and adults (mean 69ms, SD=86ms, $p<.01$): Age x UP, $F_1(1, 35)=0.88$, $p>.05$, $\eta_p^2=.03$, $F_2(1, 34)=0.50$, $p>.05$, $\eta_p^2=.01$ (Figure 1).

Errors

Children produced more errors than adults (Age, $F_1(1, 35)=4.12$, $p<.05$, $\eta_p^2=.11$, $F_2(1, 34)=3.32$, $p=.08$, $\eta_p^2=.09$; Children LUP 7.5%, SD=7.72%, EUP 11.11%, SD=10.06%; Adults LUP 5.56%, SD=3.94%, EUP 4.89%, SD=6.17%).

Correlations

For children, there was a significant negative correlation between lexical competition (LUP RT – EUP RT) and phoneme awareness ($r(20)=-.47$, $p=.04$) but not with vocabulary ($r(20)=-.33$, $p=.16$) or age ($r(20)=-.38$, $p=.10$). There were no significant correlations for adults (phoneme awareness, $r(17)=-.06$, $p=.82$; vocabulary, $r(17)=.13$, $p=.63$; age, $r(17)=.13$, $p=.62$).

There was also a significant positive correlation between pause detection item RT and AOA ratings (collapsing across LUP and EUP conditions) for children ($r(36)= .35$, $p=.03$) that did not reach significance for adults ($r(36)= .29$, $p=.09$). Thus, children were faster to detect pauses in words that were acquired earlier in development.

Sentence Processing

Mean pause detection RTs and errors for each condition are shown in Table 2. Mixed-design ANOVAs were performed with UP (LUP, EUP) and Context (constraining, neutral) as the within-subject factors and Age as the between-subjects factor.

RT

Children were slower than adults (Age, $F_1(1, 35)=36.02$, $p<.001$, $\eta_p^2=.51$, $F_2(1, 34)=82.52$, $p<.001$, $\eta_p^2=.71$) and participants were slower for the LUP than the EUP condition (UP, $F_1(1, 35)=35.37$, $p<.001$, $\eta_p^2=.50$, $F_2(1, 34)=15.19$, $p<.001$, $\eta_p^2=.31$). Across UP conditions children showed a larger context effect (faster responses to constraining than neutral conditions) (mean difference 85ms, SD=105ms, $t(19)=3.61$, $p<.01$) than adults (mean difference = -20ms, SD=131ms, $t(16)=0.63$, $p>.05$): Context x Age, $F_1(1, 35)=7.34$, $p<.01$, $\eta_p^2=.17$, $F_2(1, 34)=2.27$, $p>.05$, $\eta_p^2=.06$. For the LUP condition, constraining sentences were responded to faster than neutral sentences (mean difference 136ms, SD=202ms, $t(36)=4.11$, $p<.001$) whereas for the EUP condition, neutral sentences were responded to faster than constraining sentences (mean difference 63ms, SD=176ms, $t(19)=-2.17$, $p<.05$): UP x Context, $F_1(1, 35)=18.74$, $p<.001$, $\eta_p^2=.35$, $F_2(1, 34)=7.49$, $p<.01$, $\eta_p^2=.18$. The UP x Context interaction was significant for children ($p<.05$) and adults ($p<.001$). Both groups showed significant context effects for the LUP condition; however, in contrast to children, adults showed significantly faster responses for neutral than biased contexts for the EUP condition ($p<.05$).

Errors

Children made more errors than adults (Age, $F_1(1, 35)=13.32$, $p<.001$, $\eta_p^2=.28$, $F_2(1, 34)=14.54$, $p<.01$, $\eta_p^2=.30$) and participants made more errors for neutral than biased sentences (Context, $F_1(1, 35)=5.87$, $p<.05$, $\eta_p^2=.14$, $F_2(1, 34)=2.74$, $p>.05$, $\eta_p^2=.08$). There was a significant main effect of UP, $F_1(1, 35)=10.10$, $p<.01$, $\eta_p^2=.22$, $F_2(1, 34)=2.46$, $p>.05$, $\eta_p^2=.07$, and a significant UP x Age interaction, $F_1(1, 35)=22.52$, $p<.001$, $\eta_p^2=.39$, $F_2(1, 34)=13.59$, $p<.01$, $\eta_p^2=.29$: Children showed more errors for the LUP than EUP condition, $t(19)=4.60$, $p<.001$, but adults showed no difference, $t(16)=2.06$, $p>.05$.

Correlations

There were no significant correlations between lexical competition (LUP – EUP, across constrained and neutral conditions) and phoneme awareness (children $r(20)=.30$, $p=.19$; adults $r(17)=.38$, $p=.14$), vocabulary (children $r(20)=-.31$, $p=.18$; adults $r(17)=-.13$, $p=.60$) or age (children $r(20)=.09$, $p=.72$; adults $r(17)=.16$, $p=55$).

Discussion

Overall, the data suggest highly similar effects of uniqueness point and sentence context on early lexical activity in children and adults. Across both groups, pause detection latencies were slower for words with later uniqueness points that have more competitors at the end of their initial fragments in both single-word and sentence contexts. This suggests that early lexical competition during familiar word recognition is well established in the developing lexicon by 7 years. Interestingly, there were no developmental differences in the magnitude of this effect for single-word processing, with the effect size for children being just as robust as for adults. In a sentential context the magnitude of the lexical competition effect was again similar in RTs in both groups; however, only children showed the effect in errors, likely due to the minimal errors produced by adults. Together, these findings suggest that children process the incoming speech signal sequentially and their speech processing is characterised by competition with similar sounding lexical entries similar to adults. Hence, when using the on-line pause detection paradigm, we present clear evidence that children show lexical competition effects early in speech recognition. The fact that the LUP and EUP word lists were closely matched for global phonological neighbourhood size (see Appendix B) but differed on an incremental measure of neighbourhood (uniqueness point) strengthens our claim that the lexical competition effect reflects incremental lexical competition from multiple word candidates that are activated from partial speech input rather than competition from whole word competitors that are activated after word offset.

There was no strong evidence that lexical competition was associated with vocabulary size in this study. It is possible that lexical competition effects obtained from repetition and gating tasks may be more dependent on awareness of the existing knowledge base than pause detection, hence accounting for stronger associations between vocabulary knowledge and lexical competition effects in previous studies. Furthermore, since we ensured that children knew the competing words, the potential influence of broader vocabulary knowledge on lexical activity maybe weakened. There was, however, a significant positive correlation between phoneme awareness and single-word lexical competition for children: Larger lexical competition effects were associated with a greater ability to delete phonemes from familiar words. One tentative explanation for this is that children with more advanced phoneme awareness may have richer and/or more stable lexical representations that are more likely to engage in competition during spoken word recognition. However, these correlations need to be replicated with larger sample sizes that have greater variability in background language variables.

Pause detection latency (collapsed across LUP and EUP single-word conditions) was also positively correlated with AOA of the words. This correlation reached significance for children but not for adults, suggesting that, particularly for children, pauses are detected faster when they are inserted in earlier acquired words. Words acquired earlier in development likely have richer more established lexical representations that are retrieved more efficiently, thus leaving more resources available for pause detection and resulting in the faster latencies. Arguably, the correlation between AOA and pause detection RT was less likely to reach significance in the adult sample since for them the words were all relatively early-acquired.

The results also provide new evidence on the interactivity-autonomy debate during development, replicating the Context x UP interaction reported in Mattys et al. (2005). Both groups were faster to detect pauses in words with LUPs when the context was biased than neutral; no such effect was obtained for words with EUPs. This suggests that context can reduce lexical activity as the speech stream unfolds in children as in adults, supporting interactive models. In contrast to Mattys et al (2005) adult latencies for neutral contexts were significantly faster than latencies for constraining context (Table 2). This is a somewhat surprising and perhaps spurious result that needs further replication, particularly since the present study is the first attempt at replicating Mattys et al (2005). However, one tentative explanation may be that constraining context slows subsequent lexical processing when more information is provided than is necessary for word recognition. More specifically, when a word with an early uniqueness point is preceded by a highly constraining sentence, greater levels of associated semantic knowledge and prior episodic knowledge may be activated than when the sentence is neutral. This increase in lexical activity caused by the richer sentence context may interfere with pause detection latency for EUP words, which are already processed rapidly. In contrast, it is plausible that the constraining sentence context for the LUP condition works to reduce pause detection latency since it results in a decrease in activation for context irrelevant competitors.

Previous studies have provided strong evidence for on-line incremental lexical competition in adults (Gaskell & Dumay, 2003; Mattys & Clark, 2002): Our findings provide the novel evidence that children aged 7-8-years-old show the same early lexical competition effects as speech input is processed. This finding has clear theoretical importance since previous lexical competition effects documented in children may have reflected off-line lexical activity rather than a continually updated competition process based initially on partial information. We have also demonstrated that early competition effects can be modulated by a key parameter shown to be influential in adult studies, namely, the semantic compatibility between lexical candidates and their preceding sentence context. Experiment 2 moves on to explore a second parameter of lexical competition, that is, whether lexical competition for existing words is modulated following exposure to new competitors and indeed whether lexical competition can be used as an index of whether a new word has been 'lexicalised' in children as in adults. Arguably, this provides a stronger test of the UP effect demonstrated in Experiment 1. Although the LUP and EUP word lists used in Experiment 1 were well matched on a number of critical variables, we cannot rule out that the word lists differed on an uncontrolled linguistic variable and that this influenced the competition effect (cf. Bowers et al., 2005). Thus, Experiment 2 examined the UP effect by introducing participants to novel competitors of existing words with EUPs and then comparing pause detection latencies for existing words for which a new competitor had been taught against control words. Crucially, the 'basewords' and control words were rotated across participants and thus any lexical competition effects cannot be attributed to differences between stimulus lists.

Experiment 2

Experiment 2 examined the time-course of novel word learning using the emergence of lexical competition between novel words and existing words as a marker that the novel words have been integrated into the lexicon (cf. Gaskell & Dumay, 2003). Children and adults were exposed to the same novel nonwords as used in Brown et al (in press). For adults, we hypothesised that lexical competition effects for existing words (e.g., biscuit) would emerge 24-hours after exposure but not immediately (Dumay & Gaskell, 2007; Dumay, Gaskell, & Feng, 2004; Gaskell & Dumay, 2003). Using lexical decision, Brown et al (in press) reported that children showed lexical competition immediately *and* 24-hours after exposure to novel words. However, these latter results were weak and need replication. Using pause detection as a more sensitive on-line measure, we retested the hypothesis that lexical integration requires a consolidation period in children as in adults.

Method

Participants

Eighteen children (mean age 7.87 years, SD=0.27 years, range 7.42 – 8.16 years; 9 males) were recruited from primary schools. Informed parental consent was obtained for all children. Eighteen adults (mean 19.31 years, SD=0.73 years; 6 males) were recruited from the University of York. Children completed the same measures of receptive vocabulary and phoneme awareness as in Experiment 1: mean receptive vocabulary standard score 104.78 (SD=8.75), mean phoneme elision scaled score 10.56 (SD=2.33). Participants were native English speakers, had no reported learning disabilities, and had normal or corrected-to-normal vision and hearing.

Materials

Twenty-six stimulus triplets were selected from Brown et al (in press), comprising one existing “baseword” (bramble), one fictitious novel word (brambooce) and one foil nonword (bramboof) used as a distracter in the 2-alternative forced choice (2AFC) task (see Appendix D). Basewords had UPs at or before the final vowel, were mono-morphemic and were selected to be familiar to children aged 7-8 years old. Foil nonwords were derived by changing the final consonant clusters of the corresponding novel words. Two lists of 13 stimulus triplets (List 1 and List 2) were formed with basewords matched for AoA, number of syllables/phonemes, frequency, and acoustical duration (ms). One list was used in training and the other was left untrained as a control condition for the pause detection task. Thus, in the pause detection task half of the words (n=13) had a potential new competitor as a result of exposure whereas the other half (n=13) did not. The recordings from Brown et al (in press) were used. All stimuli had been recorded on a Pioneer PDR 509 system by a female native English speaker.

Design

All children were exposed to the novel words (List 1/2) and then completed the pause detection, cued recall, and 2AFC tasks immediately after and 24 hours later.

Training tasks

Children were exposed to each novel word 18 times in two phonological tasks (following Brown et al., in press). Stimuli in both tasks were presented via headphones and tasks were run on the same laptop as used in Experiment 1 using DMDX (Forster & Forster, 2003). Feedback was provided during practice trials.

(i) Phoneme monitoring

Participants listened to each novel word and indicated whether a pre-specified phoneme was present at any position in the word. Five practice trials were administered. There were 6 blocks of experimental trials with the target phonemes /p/, /t/, /d/, /s/, /m/, and /b/ in this order. Each novel nonword occurred 12 times, twice per block. During each block the target phoneme and a picture of a highly frequent object beginning with that phoneme were displayed centrally on screen (e.g., pig for /p/), with images of a happy and sad face displayed in the bottom left and right corners of the screen respectively, above the response buttons. The inter-trial interval was 500ms. Instructions emphasised accuracy.

(ii) Phoneme segmentation

Children were asked to listen to each novel word, repeat it, and then say the first (Block 1) or the last sound (Block 2). Novel words were presented three times per block in a randomised order. Three practice trials were administered before each block. Accuracy was recorded. Novel word production was introduced into the training regime of this experiment in contrast to previous experiments (e.g., Brown et al., in press; Gaskell & Dumay, 2003; Dumay & Gaskell, 2007) for a number of key reasons. Not least, when children and adults learn a new word they tend to produce it. Production was also deemed as important as a means to ensure that children processed the new phonological input correctly. Furthermore, standard phoneme segmentation tasks used to measure phoneme awareness typically require children to repeat the word aloud before isolating phonemes. Previous research suggests that representations used in language production and perception may be shared (e.g., Schiller & Meyer, 2003) and hence production information may be necessary for the formation of complete lexical representations.

Lexical competition task

Participants heard 13 basewords for which a novel competitor had been trained (competitor condition) and 13 for which no novel competitor had been trained (control condition). In both conditions, half the words contained a 200ms pause. Four versions were used so that each item was equally represented in the four cells of the design (competitor, pause present; competitor, pause absent; control, pause present; control, pause absent cf. Dumay & Gaskell, 2007). Participants indicated via button-press whether a pause was present or absent for each word. For the experimental items, pauses were inserted before the second vowel offset if the following consonant was a voiceless plosive and just after this vowel otherwise. Fillers were 26 bisyllabic words (half with pauses inserted at varying positions in the words). Pauses appeared in 50% of trials. Latency was measured from pause onset.

Control tasks

(i) *Ensuring participants learned the novel words*

A two alternative forced choice task (*2AFC*) and a *cued recall* task were administered to ensure children had learned the phonological forms of the novel words to an extent such that lexical competition between novel and existing words would be plausible. Corrective feedback was not provided for either task.

In the *2AFC task*, participants heard the novel words and their corresponding foils and indicated which item had been heard during training. Participants listened to both items before responding. Participants pressed the left button (for the first word) and the right button (for the second word) on the gamepad to indicate their response, with the numbers 1 and 2 presented on the left and right sides of the screen respectively. Accuracy was recorded. The order of the novel word – foil word pairs was randomised across participants, as was the order of the two items within each pair. Percent correct responses (Table 3) were entered into a mixed-design ANOVAs with Session (1, 2) as a within-subjects factor and Age (Children, Adults) and List (1, 2) as between-subject factors. Participants recognised more novel words 24-hrs after exposure than immediately (Session, $F_1(1, 32)=16.35$, $p<.001$, $\eta_p^2=.34$, $F_2(1, 14)=14.82$, $p<.01$, $\eta_p^2=.51$); this difference was significant for children ($p<.01$) and adults ($p<.01$). Adults recognised more novel words than children (Age, $F_1(1, 32)=18.06$, $p<.001$, $\eta_p^2=.36$, $F_2(1, 14)=11.59$, $p<.01$, $\eta_p^2=.45$). Greater improvements in recognition scores were seen for children than adults (by items) (Session x Age, $F_1(1, 32)=2.35$, $p>.05$, $\eta_p^2=.07$, $F_2(1, 14)=2.58$, $p>.05$, $\eta_p^2=.16$).

In the cued recall task participants heard the first CVC syllable (e.g., bram) of the 13 novel words from the exposure phase and were asked to complete the cue with one of the new words. Cues were replayed if required. If participants recalled a real word they were reminded to try to recall one of the new words. Participants' responses were recorded. Percent correct responses (Table 3) were entered into a mixed-design ANOVAs with Session (1, 2) as a within-subjects factor and Age (Children, Adults) and List (1, 2) as between-subject factors. Participants recalled more novel words 24-hours after exposure (Session, F_1(1, 32)=153.38, p<.001, η_p^2=.83, F_2(1, 24)=194.75, p<.001, η_p^2=.89); this was significant for children (p<.001) and adults (p<.001). Adults recalled more than children (Age, F_1(1, 32)=18.95, p<.001, η_p^2=.37, F_2(1, 24)=25.75, p<.001, η_p^2=.52). Children showed a greater improvement 24-hours after exposure (mean difference 43.16%, SD=18.11, p<.001) than adults (mean difference 20.51%, SD=12.09%, p<.001): Session x Age, F_1(1, 32)=19.41, p<.001, η_p^2=.38, F_2(1, 24)=29.36, p<.001, η_p^2=.55). Across Session 1 and 2 participants recalled more novel words in List 1 (mean 59.40%, SD=18.29%) than List 2 (mean 44.23%; SD=24.26%) (List, F_1(1, 32)=6.75, p<.05, η_p^2=.17, F_2(1, 24)=9.02, p<.01, η_p^2=.27). Similar improvements were seen at Session 2 regardless of whether the 2-AFC task was administered before (mean improvement for children=5.33 words, SD=2.50, p<.001; adults=2.44, SD=1.33, p<.01) or after cued recall (children=5.89, SD=2.32, p<.001; adults=2.89, SD=1.83, p<.01).

Together the results of the *2AFC* and *cued recall* tasks suggest that children and adults had acquired good knowledge of the novel words immediately after learning and that their ability to recognise novel words improved at the 24-hr retest (Brown et al., in press; Church & Fisher, 1998; Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; Houston et al., 2001; Jusczyk & Aslin, 1995; Jusczyk & Hohne, 1997). Consistent with previous research, this suggests that offline consolidation functions to enhance and/or stabilise new phonological representations. In comparison to adults, children showed significantly greater improvements in recall over 24 hours and a trend for greater improvements in recognition. However, recognition immediately after training was near ceiling for adults which potentially masked improvement. Furthermore, lower recall scores at the immediate retest for children may have given them more room for overnight improvement.

(ii) *Ensuring familiarity with the basewords*

A picture-matching task was administered to ensure children were familiar with the basewords. For each trial, one target (e.g., bramble) and three distracters (selected from www.fotosearch.com/clip-art) were displayed in a quadrant on the screen (Brown et al., in press). A target baseword was played through headphones and the participant pointed to the matching picture. Distracters were matched on AoA to the basewords (according to the MRC Psycholinguistic Database). Trial order was randomised but the same distracter images always occurred with the same target and the position of these four images on screen remained constant. Target pictures were equally distributed across quadrants. Children's accuracy was at ceiling (mean total correct = 12.39/13, SD=0.61).

Procedure

Session 1 comprised training, followed by pause detection, cued recall and 2AFC. The cued recall and 2AFC tasks were administered in a counterbalanced order to examine the influence of exposure in the 2AFC task on cued recall performance. Session 2 comprised pause detection, cued recall and 2AFC tasks (in the same order as Session 1), picture matching and the two standardised tests. The mean time elapsing between sessions was 23:52 (SD=00:51) for children and 23:55 (SD=01:02) for adults (p>.05). Half of the participants received both sessions in the morning and the other half received them in the afternoon, meaning that any effects of circadian factors are eliminated as a confound.

Results

Training

Children made significantly more phoneme monitoring errors (mean 19.87%, SD=11.26%) than adults (mean 7.41%, SD=3.46%), F_1 (1, 34) = 15.98, p<.001). There was no difference between stimulus lists for children, F_1(1, 16)<1, or adults, F_1(16)<1. Participants performed near ceiling for novel word repetitions and initial and final segmentations. Children made more repetition errors (mean 4.91%, SD=4.88%) than adults (mean 0.78%, SD=2.24%), p<.05. However, children made fewer segmentation errors (mean 11.25%, SD=9.0%) than adults (mean 21.94%, SD=10.17%), p<.05, possibly due to children being more practised at phonics tasks. There was no difference between stimulus lists for children, t(16)<1, or adults, t(16)<1.

Pause detection

Outlier removal (as in Experiment 1) discarded a mean 1.79% (SD=3.39%) items for children and 1.57% (SD=3.04%) for adults (p>.05). Latencies (for correct responses) and errors were entered into separate mixed-design ANOVAs with Condition (baseword, control) and Session (1, 2) as within-subject factors and Age (Children, Adults) and List (1, 2) as between-subject factors. Pause detection RT and errors were averaged across pause-present and pause-absent trials (following Gaskell & Dumay, 2003; Dumay & Gaskell, 2009).

(i) RT

Children produced longer latencies than adults (Age, F_1(1, 32)=64.23, p<.001, η_p^2=.67, F_2(1, 24)=532.08, p<.001, η_p^2=.96). Crucially, latencies did not differ between baseword and control conditions immediately after exposure (mean difference -21ms, SD=124ms, p>.05) whereas 24-hours post exposure latencies for were significantly longer for baseword than control conditions (mean difference 71ms, SD=113ms, p<.01): Condition x Session, F_1(1, 32)=12.92, *p*<.01, η_p^2=.29, F_2(1, 24)=3.09, *p*=.092, η_p^2=.11 (Figure 3). The Condition x Session x Group interaction was not significant, F_1(1, 32)=0.15, *p*>.05, η_p^2=.01, F_2(1, 24)=0.01, *p*>=.05, η_p^2=.0, confirming that both groups showed a similar pattern of no lexical competition immediately after exposure (children mean difference 5ms, SD=140ms, *t*(17)=0.14, *p*>.05; adults mean difference -47ms, SD=103ms, *t*(17)=-1.92, *p*=.07) but significant lexical competition after 24-hours (children mean difference 106ms, SD=132ms, *t*(17)=3.40, *p*<.01; adults mean difference 35ms, SD=79ms, *t*(17)=1.88, *p*=.07). However, when collapsing across sessions, children showed significantly larger lexical competition effects (mean difference 55ms, SD=104ms, *p*<.05) than adults (mean -5ms, SD=70ms, *p*>.05): Condition x Age, F_1(1, 32)=4.37, *p*<.05, η_p^2=.12, F_2(1, 24)=2.72, *p*=.11, η_p^2=.10. There were no other significant main effects or interactions.

(ii) Errors

Children showed more errors overall (mean 14.85%, SD=12.75%) than adults (mean 5.35%, SD=3.65%) (Age, F_1(1, 32)=9.78, *p*<.01, η_p^2=.24, F_2(1, 24)=46.33, *p*<.001, η_p^2=.49). Immediately after exposure children showed substantially more errors (mean 17.31%, SD=14.65%) than adults (mean 4.50%, SD=1.57%), *p*<.01, but 24-hours post exposure children showed only marginally more errors (mean 12.38%, SD=7.19%) than adults (mean 6.19%, SD=4.19%), *p*=.06: Session x Age, F_1 (1, 32)=5.65, *p*<.05, η_p^2=.15, F_2 (1, 24)=6.16, *p*<.05, η_p^2=.11.

Discussion

Once again, the results suggest a remarkable similarity in the lexical competition profile for children and adults. Lexical competition effects of the newly learned items were obtained 24 hours after exposure to the novel words but not immediately. Hence, Experiment 2 demonstrates how early lexical competition emerges after consolidation when a words UP has been increased as a result of introducing a novel competitor. Importantly, this is the first evidence that children, like adults, require a period of consolidation before a new word is integrated into the existing lexicon. The results also have important methodological implications, suggesting that the on-line pause detection paradigm can provide a sensitive on-line measure of changes in lexical activity following word learning in children.

Arguably, this evidence of early lexical competition from novel competitors presents a stronger case for the UP effect in children than Experiment 1. Experiment 1 compared two word lists differing in UP and although great care was taken to match these lists on a number of critical variables the effects may nevertheless remain vulnerable to stimulus matching confounds (Bowers et al., 2005). Since the same words were used as basewords and control words in the pause detection task of Experiment 2 (counterbalanced across participants), these effects cannot be attributed to differences in acoustic or linguistic characteristics between words in each condition.

Overall, lexical competition effects were larger for children than for adults (for both RTs and errors). The generally slower RTs in children could have inflated the difference between conditions (Chapman, Chapman, Curran & Miller, 1994). Alternatively, children may experience more lexical competition during word learning than adults (similar to Brown et al., in press). Connectionist models conceive of words as “attractors” in the child’s “language state space” that vary in their strength of activation (Elman, 1995). More recently acquired attractors are considered as more vulnerable to competing processes than older, established attractors (Cohen, Dunbar, & McClelland, 1990; Evans, 2007; Magnuson et al., 2003; Mainela-Arnold, Evans & Coady, 2008). Therefore, greater competitor activation might be seen in children than adults if they have newly established lexical attractor states for the basewords. There may also be methodological reasons why the lexical competition effects were smaller for adults. For instance, fewer items were trained than in previous adult studies (e.g., Dumay & Gaskell, 2007; Gaskell & Dumay, 2003), which may have decreased the power needed to detect effects. Moreover, participants produced the novel words during training in the current study which has been shown to attenuate the extent to which novel lexical representations engage sublexical representations in adults (Leach & Samuel, 2007).

General Discussion

This study was carried out to determine whether words engage in early on-line lexical competition as the speech stream unfolds in children. We carried out two experiments to examine early lexical competition effects for existing words in children and whether this lexical activity is modulated on-line (by sentential context and by introducing a new competitor to the lexicon). We examined these features of lexical processing in children because they have proved to be key factors in determining the course of lexical competition in adults, thus enabling theoretical and empirical comparison across development. The pause detection paradigm was used to provide a comprehensive analysis of the on-line lexical competition process for spoken words in development. There were three key findings. First, children and adults showed comparable incremental lexical competition effects during spoken word recognition in isolation and in sentential context. Second, the lexical competition that arises as words are processed can be modulated by semantic context on-line in children, thereby informing developmental models of lexical-contextual integration. Third, Experiment 2 provides the first demonstration that the lexical competition environment in children is altered as new words are learned, but, as in adults, these modulatory effects are not observed until after a period of offline consolidation.

In Experiment 1 a clear lexical competition effect was revealed for two sets of words that were matched in terms of a global measure of phonological neighbours (the number of words differing by just one phoneme anywhere in the word), but differed in an incremental measure of neighbourhood (uniqueness point). In terms of the functional architecture of children's speech recognition system, this suggests that early lexical competition is well established in the lexicons of 7-8-year-olds. This supports the view, based on adult research, that candidate lexical representations are activated sequentially and incrementally during the course of a word's perception and that lexical competition operates prior to the accumulation of a full auditory representation of a word (Gaskell & Marslen-Wilson, 1997; Marslen-Wilson, 1987; Marslen-Wilson & Zwitserlood, 1989; Zwitserlood, 1989). The existence of early lexical competition effects in children has been questioned by developmental models of lexical processing which suggest that lexical processing is more holistic in children (Charles-Luce & Luce, 1995; Dollaghan, 1994; Fowler, 1991; Jusczyk, 1993; Metsala & Walley, 1998; Metsala, 1997; Nittrouer, 1996; Walley, 1993; Ziegler & Goswami, 2005) and by findings that word representations are less well specified (Castles et al., 2007; Storkel & Rogers, 2000) and word recognition does not reach adult speeds until around 9 years of age (Ojima et al., 2011). The present results clearly demonstrate that children nevertheless show clear evidence of lexical competition early in spoken word recognition. This was evidenced by the finding that the lexical competition effect arose from heightened lexical activity as the speech stream was presented. This supports previous eye tracking studies which have also provided evidence of on-line lexical competition in children as young as 5 years during familiar word recognition (Sekerina & Brooks, 2007) and from 1.5 years during the early stages of word learning (Swingley & Aslin, 2007).

Pause detection latency was also sensitive to the modulation of lexical activity by sentence context. Children were faster to respond to words with late uniqueness points when they were embedded in sentences that were biased towards the final word rather than neutral; no such effect was obtained for words with early uniqueness points. This suggests that lexical and contextual factors are highly interactive from an early point in word processing in children (Tabossi, 1988; Van Petten & Kutas, 1987; Friederici, Steinhauer & Frisch, 1999; Henderson et al., 2011; Van Petten et al., 1999). Our results conflict with previous sentence-priming findings that suggest that children do not show adult-like sensitivity to sentence context until 9-10 years (Khanna & Boland, 2010) and 12 years (Booth et al., 2006). One possibility is that pause detection is more sensitive to the influence of context on lexical activity than sentence priming.

Using lexical competition as an index of novel word integration, this study also provides new evidence about the time-course with which a new word is acquired into the lexicon. Consistent with adult studies (Dumay & Gaskell, 2007; Gaskell & Dumay, 2003) children and adults showed lexical competition for similar sounding basewords 24-hours post-exposure but not immediately (although the 24-hour effect was marginally significant for adults). Brown et al. (in press) used lexical decision rather than pause detection and found that 7 and 12-year-olds showed lexical competition immediately and 24-hours post-exposure, although the effects in the younger group were weak. In the light of the present results, we argue that the most likely explanation for Brown et al's results is centered on the methodological demands of lexical decision and the limitations of using this task to measure lexical competition in children. Lexical decision demands metalinguistic awareness, knowledge of the linguistic stimuli being processed, a decision-making process and measures lexical activity at the end point of spoken word recognition. Furthermore, the lexical decision task used in Experiment 2 of Brown et al. (in press) used a reduced number of filler items (26 experimental words, 26 word fillers and 52 nonwords) in contrast to previous adult studies using lexical decision (e.g., Davis et al., 2009; 54 experimental words, 76 word filler and 130 nonwords). This may have increased children's awareness of the similarity between basewords and novel nonwords at both time points; thus the competition effects may have been more strategic and due to explicit awareness of the overlap between basewords and novel competitors rather than being due to automatic and implicit processes that occur earlier in speech recognition. The likelihood of strategic processing in children is also increased by their slower response times, which leave greater room for explicit awareness to influence the decision making process. Hence, in contrast to pause detection, the lexical decision task used by Brown et al. may have measured a more strategic form of competition that occurred consciously (at the end point of processing the word) and that cannot be attributed to lexical integration.

The finding that children show an onset of lexical competition from novel nonword competitors after a period of off-line consolidation provides support for the CLS account of vocabulary acquisition (Davis & Gaskell, 2009; McClelland et al., 1995; O'Reilly & Norman, 2002; Robins & McCallum, 1999). CLS models (McClelland et al., 1995) postulate two learning systems: a slow, interleaved learning system that produces dense and overlapping representations in the neocortex and a faster learning system that produces sparse representations in the medial temporal lobe. The slow, interleaved learning system is necessary to ensure that existing knowledge is not overwritten by incoming information. Because the initial neocortical memory trace is too weak to activate fully on its own in the absence of external stimulation or in response to partial stimulation, a second system is needed to bind the neocortical representation together until it has become strong enough through consolidation. In CLS models consolidation occurs in the form of gradual strengthening of the neocortical trace, during a reinstatement process where the memory trace is repeatedly reactivated over time. As the neocortical trace gains in strength with consolidation, the hippocampal representations eventually become superfluous, and neocortical memory eventually becomes independent of the hippocampus.

The data from the present study advance the CLS models by providing evidence of a dual-systems model of word learning in children. From this data alone, we cannot make claims about whether sleep is crucial for lexical integration. Sleep may have played a role in the improvement in recall and recognition of novel nonwords in Experiment 2 since previous studies have already demonstrated that 6 to 12 year old children showed improvements in declarative memory after sleep, but not after a similar time period whilst awake (Backhaus et al., 2008; Wilhelm et al,. 2008). Gomez et al., (2006) reported that infants are more likely to abstract statistical probabilities from an artificial grammar after sleep than after an equivalent period of wake but they did not directly examine the issue of word learning and lexical integration. Our current research examines whether children show improvements in recall and recognition and an increase in lexical competition 12 hours after training but only when that period includes sleep (similar to the adult findings reported by Dumay & Gaskell, 2007).

Conclusion

Pause detection has shown to be a sensitive and reliable measure of lexical activity in children. The results support the idea that lexical activation is early, competitive and flexible during spoken word recognition in children. The findings further suggest that semantic context interacts with lexical activity very early in word recognition in children. Finally, our data suggest that lexical acquisition in children is a dynamic process involving a dualmemory system with lexical competition effects for novel words emerging only after a period of consolidation. Together, these results suggest a striking similarity between processes of lexical competition in children and adults. Additional research is now needed to fully address the time-course of vocabulary acquisition in children, including the role of sleep in consolidation and lexical integration.

Footnotes

[1] To rule out that any observed difference in EUP and LUP conditions could be due to differences in acoustic rather than lexical properties of the stimuli, we carried out a small-scale control experiment to demonstrate that there is no UP effect when the lexical content of the stimuli is made unavailable. We did this by administering the same experiment to 10 adult Native French speakers (2 male; mean age 22.2 years, SD=2.44 years) who, on average, reported speaking or listening to the English language 6% of their average week (SD=0.08%). As predicted, there was no significant difference in pause detection latency between EUP (mean 1512ms, SD=212ms) and LUP (mean 1478ms, SD=309ms) conditions, $t_1(9)=0.78, p=.46$, $t_2(17)=0.89, p=.39$. Similarly there was no difference in pause detection accuracy between EUP (mean 71%, SD=23%) and LUP (mean 73%, SD=24%) conditions, $t_1(9)=-0.80, p=.44$, $t_2(17)=-0.43, p=.68$. Thus, when participants have little knowledge of the lexical content of the stimuli there is no difference in pause detection latency for EUP and LUP conditions. In fact, the RT effect was in the reverse direction. Since there is some overlap in orthography and phonology between the French and English translations of the words the participants may have been able to guess the meanings of the words to a certain extent: This further strengthens our argument that the UP effect reported in our paper is due to early automatic access to lexical information rather than acoustic differences.

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Table 1. Age, receptive vocabulary and phoneme awareness for the child and adult participants.

	Children		Adults	
	Mean (SD)	Range	Mean (SD)	Range
Age (in years)	7.69 (0.28)	7.33 – 8.19	20.08 (1.29)	18.16 – 23.66
Receptive Vocabulary (ss)	109.50 (6.87)	97 – 124	107.71 (9.90)	94 – 126
Phoneme Elision (sc)	11.45 (2.70)	8 – 18	9.65 (1.11)	7 – 11

Note. ss = standard score (mean = 100, SD = 15; normal range 85 – 115); sc = scaled score (mean = 10, SD = 3; normal range = 8 – 12)

Table 2. Mean (and SD) pause detection RTs and errors for LUP (constraining and neutral) and EUP (constraining and neutral) conditions.

	LUP		EUP	
	Constraining	Neutral	Constraining	Neutral
RT				
Children	1242 (280)	1410 (336)	1181 (246)	1182 (241)
Adults	890 (179)	988 (158)	840 (173)	702 (172)
% Errors				
Children	27.88% (14.27)	27.31% (13.19)	14.81% (10.16)	17.50% (9.12)
Adults	8.81% (9.12)	11.31% (8.43)	11.31% (9.27)	13.35% (7.10)

Table 3. Mean percent correct (and SDs) for the 2AFC and cued recall tasks, for 0-hr and 24-hr retests.

	Children		Adults	
	0-hr	24-hr	0-hr	24-hr
2-AFC (%)	68.77 (23.23)	85.92 (16.08)	91.30 (10.62)	98.69 (3.92)
Cued Recall (%)	17.54 (17.15)	60.69 (20.38)	54.31 (24.38)	74.77 (18.23)
Pause Detection				
Baseword RT	1300 (254)	1353 (252)	726 (166)	773 (206)
Control Word RT	1296 (291)	1247 (269)	772 (209)	738 (217)
Baseword Errors	2.39 (2.48)	1.44 (1.58)	0.72 (0.66)	0.78 (0.94)
Control Word Errors	2.11 (1.71)	1.78 (1.86)	0.44 (0.71)	0.83 (0.86)

Figure Headings

Figure 1. Mean pause detection RT for the LUP and EUP conditions (error bars display 95% confidence intervals).

Figure 2. Context (Neutral, Constraining) x UP (LUP, EUP) interaction.

Figure 3. Lexical competition effects at 0-hr and 24-hr retests for children and adults

Appendices

Appendix A. Eighteen items in each UP condition, the LUP competitors and the proportion of participants recognising at least one LUP competitor as a word in the lexical decision task

EUP	LUP	LUP Competitors	Proportion of participants recognising at least one competitor as a word
biscuit	advert	adventure, advent, adversity	1
blossom	bandage	banding, bandit	0.86
bramble	cabbage	cabin, cabinet	0.95
breakfast	camera	camouflage, camel	0.95
closet	carpet	carpenter	0.95
dolphin	college	cauliflower	1
fountain	compass	company	0.95
mermaid	concern	conserve, conservative	0.86
napkin	device	divide, divine, devise	0.86
parade	furnace	furniture, furnish	0.9
platform	insect	incense, inset, insecure, insensitive	0.95
potato	meringue	miraculous, marine, marina	0.95
sergeant	passage	passenger, passive, passing	0.81
siren	receipt	receive, recede	0.95
skeleton	salad	salary, salamander	0.76
squirrel	surface	surfing	0.95
tulip	uniform	unify	1
volcano	wicket	wicked, wicker	1

Appendix B. Properties of LUP and EUP words used in the analysis of Experiment 1

	LUP (n = 18) Mean (SD)	EUP (n = 18) Mean (SD)	*F*
Fragment length prior to pause (ms)	485 (132)	536 (148)	4.03, $p < .05$
Length of word including pause (ms)	1185 (158)	1202 (209)	< 1
Letter length	6.67 (0.77)	6.95 (1.11)	< 1
Syllable length	2.11 (0.32)	2.17 (0.38)	< 1
Phonological Neighbours	0.17 (0.51)	0.17 (0.38)	< 1
Familiarity	516.86 (69.74)	496.25 (83.09)	< 1
CPWD Frequency	31.65 (57.64)	42.94 (58.40)	< 1
SUBTLEX Frequency	700.24 (1036.08)	738.12 (1022.37)	< 1
Age of acquisition	5.90 (1.30)	5.57 (1.22)	< 1
Uniqueness Point	6.50 (0.86)	4.89 (0.47)	55.31, $p < .001$

Note. Due to the significant difference in fragment length prior to the pause between EUP and LUP conditions, the analysis reported in Experiment 1 for the single-word task was repeated using a only a subset of 14 items in each condition that were pairwise matched on initial fragment length (prior to the pause) (n 14 LUP initial fragment length 515ms, SD 103ms; n 14 EUP initial fragment length 529ms, SD 75ms). The same results as reported in the Results section of Experiment 1 were obtained: Age, F_1 (35) = 13.43, $p < .01$, $\eta_p^2 = .28$, F_2 (26) = 181.44, $p < .001$, $\eta_p^2 = .88$, UP, F_1 (35) = 8.94, $p < .01$, $\eta_p^2 = .20$, F_2 (26) = 7.20, $p < .05$, $\eta_p^2 = .22$, Age x UP, F_1 (35) = 0.06, $p > .05$, F_2 (26) = 0.01, $p > .05$.

Appendix C. Sentence Stimuli

LUP	Neutral	Constraining	Proportion of Related Guesses (Neutral, Constraining)	Proportion of Correct Guesses (Neutral, Constraining)
advert	While he washed the car, Ben saw the advert	While he waited for the TV program, James saw the advert	0, .95	0, .52
bandage	After he finished the lesson, the teacher noticed the bandage	After he stitched up the wound, the doctor put on the bandage	0, .95	0, .29
cabbage	Uncle David preferred the cabbage	Joe's favourite vegetable was the cabbage	.05, 1	.05, .05
camera	Jess took a look at the camera	Jo took a photo with the camera	0, .90	0, .86
carpet	Sarah admired the carpet	Meg hoovered the carpet	0, .95	0, .38
college	Jim looked at the college	Rose studied at the college	0, .90	0, .10
compass	Michael was bored, but thankfully he had a compass	Daniel was lost, but luckily he had a compass	0, .86	0, .14
concern	Richard was doing very well and was a concern	Harry worried a lot and his teacher had some concern	0, .95	0, .24
device	Fred did not understand the device	The electrician fixed the device	0, 1	0, 0
furnace	They stood and looked at the furnace	It was very hot inside the furnace	0, .48	0, .05
Insect	Richard did not like the insect	Amy got stung by the insect	0, .90	0, 0
meringue	Jane thought it was the meringue	Julie at strawberries with the meringue	0, .43	0, .05
passage	Lucy had never seen such a strange passage	To escape they ran through a dark passage	0, .71	0, .10
receipt	The teacher gave Robert a receipt	The checkout assistant gave Tom a receipt	0, .95	0, .71

salad	The workers liked lots of salad	The diet involved eating lots of salad	0, .71	0, .05
surface	It took all afternoon to finish off the surface	It took all morning to clear the roads' icy surface	0, .90	0, .62
uniform	Whilst getting ready for bed, Mark thought about the uniform	Whilst getting ready for school, Harry put on his uniform	0, .95	0, .19
wicket	The teacher told us about the wicket	The cricket ball hit the wicket	0, .76	0, .19
EUP				
biscuit	Dad opened the wardrobe and gave Matthew a biscuit	Mum opened the tin and gave Emily a biscuit	.05, .62	0 .38
blossom	The dog needed a bath; it was covered in blossom	The tree was beautiful; it was covered in blossom	0, .81	0, .14
bramble	Dennis collected nuts from the bramble	Ben picked blackberries from the bramble	.33, .71	0, 0
breakfast	Kerry likes to watch TV during her breakfast	Hannah likes to eat cereal for her breakfast	0, .90	0, .76
closet	Henry went to get his dog out of the closet	Graham went to get his coat out of the closet	0, .81	0, .14
dolphin	It was the first time Jennifer drew a dolphin	It was the first time Marie swam with a dolphin	.05, 1	0, .86
fountain	Dave got too hot because he stood next to the fountain	Geoff got soaked because he stood next to the fountain	0, .81	0, .19
mermaid	Megan saw a girl in the distance with a red coat, she must've been a mermaid	Helen saw a girl in the sea with a tail fin, she must've been a mermaid	.05, .86	.05, .86
napkin	The fireman carefully picked up the napkin	The waitress carefully folded the napkin	0, .90	0, .86
parade	People cheered as the footballers began the parade	People cheered as the marching band began the parade	.05, .43	0, .29

platform	It was going to rain so they waited on the platform	The train was coming so they waited on the platform	.19, .95	.19, .90
potato	Hayley bought a potato	Chips are made out of potato	0, .95	0, .95
sergeant	The teacher welcomed the sergeant	The soldier saluted the sergeant	0, .90	0, .10
siren	The house had a very big siren	The police car had a very loud siren	0, 1	0, 1
skeleton	The children found the skeleton	Our bodies bones make up our skeleton	0, .95	0, .90
squirrel	All the carrots had been eaten by the squirrel	All the nuts had been eaten by the squirrel	0, .71	0, .48
tulip	In the bucket of water there was a tulip	In the vase of flowers there was a tulip	0, .52	0, .10
volcano	Fred looked out and saw the volcano	Cathy jumped at the explosion of the volcano	0, .62	0, .05

Appendix D – Stimulus Triplets used in Experiment 2

	Baseword	**Competitor**	**Foil**
List 1	apricot	aprickel	apricken
	baboon	babeel	babeen
	blossom	blossail	blossain
	bramble	brambooce	bramboof
	caravan	caravoth	caravol
	cathedral	cathedruke	cathedruce
	crocodile	crocodiss	crocodin
	dolphin	dolpheg	dolphess
	fountain	fountel	founted
	lantern	lantobe	lantoke
	octopus	octopoth	octopol
	partridge	partred	partren
	skeleton	skeletobe	skeletope

	Baseword	**Competitor**	**Foil**
List 2	badminton	badmintel	badmintet
	biscuit	biscal	biscan
	cardigan	cardigite	cardigile
	daffodil	daffadat	daffadan
	dungeon	dungeill	dungeic
	napkin	napkem	napkess
	ornament	ornameast	ornameab
	parachute	parasheff	parashen
	pyramid	pyramon	pyramotch
	siren	siridge	sirit
	squirrel	squirrome	squirrope
	tulip	tulode	tulome
	yoghurt	yogem	yogell
	badminton	badmintel	badmintet
	biscuit	biscal	biscan