Early links in the early lexicon:
Semantically related word-pairs prime picture looking in the second year.

Introduction

With word meanings and word forms paired up like books in their jackets, the human lexicon is a vast and complex library. From its sparse beginnings in infancy, the lexicon incorporates thousands of words and concepts into an efficient processing system. Relationships between words provide an interconnected cross-referencing system, allowing the mature language-user to slip between the shelves with ease. For decades, the technique of 'priming' has been used to probe organisational characteristics of the adult semantic system. In the priming method, semantic context is systematically manipulated to influence on-line language processing. When sequential activation of particular items alters task performance, inferences can be made about the psychological reality of the relationship between the items – and thereby, inferences about the nature of the system.

Both visual and auditory primes are known to influence the speed of lexical access (Antos, 1979; Meyer & Schvaneveldt, 1971; Radeau, 1983) and ambiguity resolution (Swinney, 1979). Various types of semantic relationship have been demonstrated using the priming method, including word association (Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; Nation & Snowling, 1999), taxonomy (Meyer & Schvaneveldt, 1971), shared semantic features (McRae, Cree, Seidenberg, & McNorgan, 2005; Moss, McCormick, & Tyler, 1997), and instrumental relationships (Moss et al., 1995). Thus, facilitation in priming tasks can be understood as a spread of activation between related items in a semantic network (Anderson, 1983; Collins & Loftus, 1975; Meyer & Schvaneveldt, 1976).

Yet little is known about the development of the semantic system from first words and concepts, to this complex adult system. Is a system encoding relationships between concepts in place from the early stages of word learning? Or does it arise after extensive experience? Are early relationships adult-like? Or does reorganisation occur? The goal of this chapter is to review recent evidence for adult-like relationships between words in the second year using a recently developed method for investigating the organisational properties of the infant lexicon.

Models of lexicon connectivity and development

Many traditional models of network organisation propose that each word or concept acts as a discrete node, with semantic relationships forming connections between nodes. Collins and Loftus' (1975) spreading activation model, for example, characterises each concept in semantic memory as an individual node, with nodes linked by relationships, through which activity can flow. In lexical network models of this kind, the flow of activity from a 'prime' word can result in partial pre-activation of a related test word, allowing more efficient retrieval. While such models successfully capture many adult lexical processing effects, they do not typically provide a description of how newly acquired words might 'link in' to an existing network, nor when such a system arises during lexicon growth. For example, are the earliest-learned words represented as individual 'semantic islands' allowing maximum discrimination between known concepts? Or does the early semantic system encode relatedness between similar concepts from the very beginning?

Some suggestions about the early stages of semantic network development come from the mathematical growth modelling of Steyvers and Tenenbaum (2005). In their model, networks derived from word association norms demonstrate a mathematical relationship between how long a word has been part of a normative network, and how densely it is connected to other words: Early learned words are more deeply integrated in the network than recently learned words. This finding suggests that adult network connectivity encodes the sequence of network development, including the early stages of word learning. Steyvers and Tenenbaum's (2005) statistical modelling of lexicon growth uncovered a 'scale-free small-world' structure suggesting that some properties of lexicon structure are continuous throughout development. These statistical models of network growth suggest that adult-like semantic relationships may be evident very early in lexicon development, although they do not rule out the possibility of an earlier stage, during which individual words are effectively unconnected

'islands', followed by substantial lexical re-organisation.

Alternative, 'distributed' models of the adult lexicon propose a highly featured semantic space in which each concept is represented by a broad pattern of activation across numerous nodes, some of which are shared by other concepts. For example, *cat* and *dog* share nodes encoding features such as 'four legs' and 'is furry' (e.g., Cree & McRae, 2003; McRae, de Sa, & Seidenberg, 1997). Models of this kind encode semantic relatedness via overlap in feature space. Thus, activating one concept gives related concepts a 'head start' in priming contexts, due to the ongoing activation of shared resources.

As in McClelland & Rogers (2003) parallel distributed processing account of semantic learning, similarity can be encoded in the overlap of shared resources. These distributed models of semantic learning thus accommodate semantic relatedness from the beginnings of concept formation. Support for shared resources in early semantic representations can be found in the extensive literature on children's concept formation (reviewed, for example, in Mandler, 2000), and characteristic reports of young children's 'overextension' errors (e.g., Bowerman, 1987; E. Clark, 1973).

While theories of semantic development account for semantic relatedness early in conceptual development, there is little evidence to suggest how the conceptual system develops a fully functional interface with word forms. As conceptual representations are mapped onto words to in the lexicon, the nature of word-to-word relationships in the lexicon is an important, yet relatively unexplored domain. From a word learning perspective, Hills et al.'s (2009) network modelling of normative toddler vocabulary growth suggests that semantic features such as 'has legs' or 'is furry' allow new words to link into a semantic network consisting of very few words. At different stages in lexicon growth, their model shows some words as isolated lexical islands, with others clustering together into proto-categories, and theme-groups, suggesting that organisation may be variable in the early stages, but lead to systematic adult-like semantic organisation with scale. However, Hill's et al.'s (2009) model takes its data from a normative toddler vocabulary, and is unable to assess whether the feature-based relationships are psychologically valid in the individual learner's lexicon. Are they adult-like? Would they influence performance in an on-line language-based task?

A methodological conundrum

Traditional sequential priming studies rely on adult reaction times (RTs) during behavioural tasks such as lexical-decision, categorisation, and word-reading – tasks typically employed over large sets of stimuli. Despite the ubiquity of priming methods in the adult semantic memory literature, no current behavioural method is widely accepted for investigating semantic relationships in the lexicons of children below the age of five. Barriers to the use of adult methodologies in early development include participants' limited attention spans, relatively small vocabularies, lack of explicit metalinguistic knowledge (e.g., whether a string of sounds is a 'word'), and inability to follow complex instructions.

A small number of auditory priming methodologies have been extended for use with toddlers and school-aged children. Primed lexical decision, object decision and picture naming tasks have shown that semantic, thematic and associative relationships between words can influence reaction time for normally developing children in the early school years (Carr, McCauley, Sperber, & Parmelee, 1982; Hashimoto, McGregor, & Graham, 2007; Nation & Snowling, 1999), and a primed verbal memory task has shown that associative relationships can affect recall accuracy for 3- to 4-year-olds (Krackow & Gordon, 1998). These studies suggest that children as young as 3 years-of-age demonstrate aspects of adult-like semantic memory. However, the applicability of these methods to even younger populations remains limited by the complexity of the tasks employed. Priming for toddlers requires an intuitive experimental task without complex instructions, which can also accommodate the high temporal accuracy typically required to observe priming effects.

In an alternative approach, researchers in the field of electroencephalography have sought to replicate adult patterns of brain activity in studies designed for toddlers. The 'N400 component' in adult event-related potentials (ERPs), is understood to index semantic congruency (Kutas & Hillyard, 1980), semantic relatedness (Federmeier & Kutas, 1999) and category organisation (Heinze, Muente, & Kutas, 1998). In recent studies seeking a toddler analogue of the N400 component, Friedrich & Friederici (2004, 2005) presented toddlers with nouns while they looked at a single picture on screen. Toddlers' ERPs following the onset of the spoken word included a component similar to the adult N400, which was large in the presence of a mismatch between the picture and the label, small in the presence of a match, and midway between these values for a mismatch drawn from the same semantic category. Thus toddlers looking at a picture of a cat were less sensitive to a mismatch when they heard a word like *dog*

than they were when they heard a word like *chair*. The authors interpret their findings as a demonstration of adult-like 'graded semantic sensitivity' in a priming task.

However, certain features of the experimental design limit the applicability of these findings to the standard priming literature. Firstly, the Friedrich and Friederici task investigates neural responses to language while semantic information from the picture is still available. The response thus indexes a 'match' between the auditory string and the ongoing picture. Many studies in the sequential priming literature attempt to distinguish automatic priming effects (in which the prime pre-activates the target *prior* to target activation) from strategic priming effects (which can include backwards priming from the target to the prime *following* target activation). The automaticity of a priming effect is thus more difficult to interpret when one of the stimuli remains available continuously.

Torkildsen and colleagues (2007) addressed the sequential aspect of lexical processing more directly in an auditory-only toddler ERP study. When 24-month-olds were presented with pairs of words in a sequential priming paradigm, the ERP following the onset of the target word differed according to whether the prime and target were members of the same category. This finding suggests that toddlers' on-line language processing is indeed influenced by preceding auditory context. However, the authors acknowledge that it is difficult to tell what cognitive correlate these ERP signatures might index in terms of the ease or speed of linguistic processing. In adult studies, it is possible to combine ERPs with behavioural responses, and thereby assess how cortical activity relates to cognitive outcomes. Without a behavioural correlate to the toddler N400 effect, it is unclear whether this component reflects adult-like semantic relatedness, or arises from a different process.

An additional complication for toddler ERP studies is the necessity to control physical differences between stimuli. Every participant is exposed to large numbers of stimuli, and all stimuli are included in the analysis of all participants. Thus, the ERP method makes it difficult to take into account whether individual toddlers understood, or were familiar with individual words. Consequently, any appearance of graded sensitivity to a 'within category mismatch' (e.g., hearing *dog* while looking at a picture of a cat) may actually be the outcome of pooling data of different types. That is to say, toddlers who understood both *dog* and *cat* may have registered the word as a mismatch to the picture. Yet, toddlers who only understood only one of the two words may have accepted the pairing as a 'match' through overextension. A mean drawn from these two populations would produce a value midway between 'match' and 'mismatch', giving the appearance of graded sensitivity.

It thus remains to be seen whether adult-like primed processing effects can be replicated in an on-line behavioural task for toddlers, in which item-level sensitivity is achievable. If toddlers' behaviour is affected by verbal context in sequential word presentation, it would provide strong support for a model of lexicon development which includes adult-like semantic organisation from a very early age. It is necessary, therefore, to employ a toddler-friendly behavioural task in which stimulus presentation can be systematically varied to produce a priming context, and which uses ease and speed of lexical comprehension as an index of online language processing.

The inter-modal preferential looking (IPL) task, first used by Golinkoff et al. (1987), is a free-looking task for toddlers, in which a pair of pictures is presented, and eye gaze monitored while auditory stimuli are introduced. When an image is labelled, toddlers' looking behaviour shows an increase in preference for the named image (Reznick, 1990), and a tendency to initiate fixations away from pictures mismatching the label (Swingley & Fernald, 2002). The free-looking task is a flexible framework which is sufficiently sensitive to index comprehension of individual words, as well as toddlers' sensitivity to minor manipulations in picture typicality (Meints, Plunkett, & Harris, 1999; Meints, Plunkett, Harris, & Dimmock, 2002), and phonological specificity (Fernald, Swingley, & Pinto, 2001; Mani & Plunkett, 2007; Swingley & Aslin, 2007; White & Morgan, 2008), to mention just a few of factors that have been investigated. Contemporary implementations of IPL employ offline frame-by-frame analysis of video recordings, thus achieving high temporal accuracy. This infant method shares many similarities with the adult 'Visual World' paradigm, in which adults' eye movements to an array of pictures reflect the time course of online language processing (e.g., Huettig & Altmann, 2005; Huettig & McQueen, 2007; Kamide, Altmann, & Haywood, 2001; Yee & Sedivy, 2006).

In this chapter we describe a recent adaptation of the IPL method first described by Styles & Plunkett (2009a), which accommodates the sequential auditory presentation of adult priming studies, and employs a period of free-looking in the test phase of the trial. To create a priming context, words are presented prior to the onset of the picture pair. This ensures that lexical access begins in the absence of semantic information from the visual domain. The free looking task involves implicit processing of the auditory stimuli, but has an overt behavioural outcome (eye-gaze). This words-before-

pictures design allows us to ask a variety of questions: For example, does relatedness between known words influence the ease and speed of toddler's lexical comprehension? Does the locus of the priming effect reside in the relationship between the prime word and the target word, or between the prime and the picture, or both? Are any observed priming effects excitatory or inhibitory?

The Words Before Pictures Task

In order to validate the sequential auditory priming approach, Experiment 1 presents an un-primed IPL task which acts as a baseline for the words-before-pictures stimulus organisation. As illustrated in Figure 1.1, this experiment assesses whether a word beginning prior to picture presentation generates a sufficiently stable internal representation for referent identification, in a fast-paced task.

A second experiment introduces sequential auditory priming[1]. During the auditory phase of the trial, lexical primes precede all target labels. In half of the trials, primes and targets are related by taxonomy and association, in half, they are unrelated. The primary hypothesis is that when the prime and target word are related, lexical access of the target word will be enhanced relative to the unrelated condition: If the semantic system has adult-like connectivity at this age, toddlers are predicted to show more interest in the named target picture (due to greater activation of the concept), and to identify the named target picture faster (due to pre-activation of the concept). As illustrated in Figure 1.2, this priming effect may arise out of spreading activation/resource sharing at a lexical or conceptual level of representation, or some combination of both. However, is possible to ascertain whether the predicted semantic relationships influence the ability to process a spoken word and to perform a picture-matching task. As illustrated in Figure 1.3, a third experiment examines whether the prime word alone is sufficient to generate interest in the target, if it remains unnamed.

Experiment 1

In order to validate responses to pictures in a primed context, it is critical to provide a baseline for toddlers' performance in an un-primed version of the proposed task. As noted above, the priming task has no explicit instructions, and relies on the tendency shown by both toddlers and adults to preferentially fixate a picture when

it is named. However, the task employed here presents the target label shortly before the onset of the pictures, and there are a number of reasons to predict that the novel stimulus arrangement might generate a different outcome. First, given the age of participants (18- and 24-month-olds), the abrupt onset of the visual stimuli might disrupt normal processing, causing the target word to be 'erased' by picture processing. Second, as standard implementations of IPL include a long picture familiarisation phase prior to word onset, toddlers might need to explore both pictures for some time before they are able to accumulate a clear preference for the named target. Third, although toddlers are able to demonstrate rejection of a mismatching picture by shifting their eyes away quickly (Swingley & Fernald, 2002), this skill has only been demonstrated when toddlers were already fixating the picture at the onset of the target label. Toddlers may not have the same motivation to switch fixation if the word is presented before the picture.

Concerning the first possibility, previous picture-first studies have demonstrated that toddlers as young as 18 months-of-age can extract sufficient acoustic information from the first 300 ms of a word to correctly identify its referent, even if the rest of the word is omitted (Fernald et al., 2001). In the present experiment, a stimulus onset asynchrony of 400ms from the onset of the target label to the onset of the picture-pair was selected to ensure that if toddlers' auditory processing is disrupted by picture onset, they would still hear enough of the target word to correctly identify a matching picture.

In order to address concerns about whether named pictures will attract preferential gaze in the short
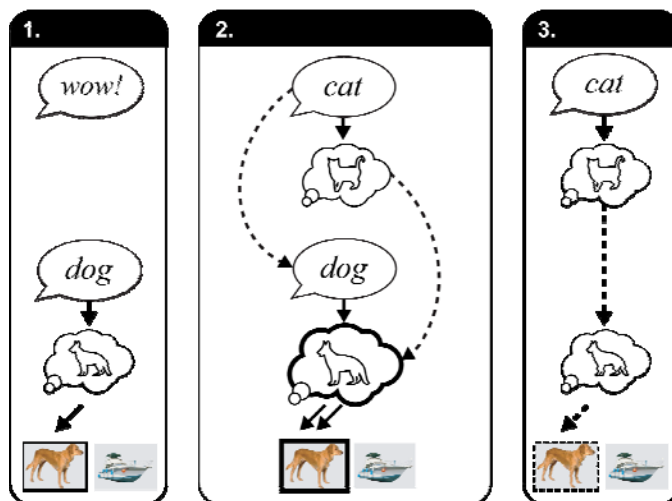

Figure 1. Schematic of lexical processing models for three experiments. A. in Experiment 1, the target label activates a representation allowing the target picture to be identified. B. in Experiment 2, two different kinds of relationship between the prime and the target could increase target discrimination – broad (overlapping) representations, or discrete (interlinked) representations. C. in Experiment 3, the overlapping representation model is assessed, by changing the stimulus organisation to include only the auditory prime, without the target label.

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[1] Experiment 2 has been previously presented in Styles & Plunkett (2009b). Here we present a re-analysis of the original experiment in a broader context to examine the important question of the nature of the priming effects observed. This issue was not fully addressed in the original study.

time available, and whether toddlers will be motivated to reject mismatching pictures quickly, two measures of eye-gaze will be used. The first assesses relative picture preference over the whole presentation period, and the second looks at the micro-structure of eye gaze within the trial, assessing reaction time following the first fixation. Using both large- and small-scale measures of eye-gaze provides a nuanced investigation of the time-course of lexical access in the novel stimulus arrangement, and the relative interest labels invoke in the as-yet-unseen pictures. If 18-month-olds and 24-month-olds' comprehension of the target words is undisrupted and the timing appropriate, toddlers are predicted to accumulate more looking time to the named target picture than the unnamed distracter. Toddlers are also predicted to disengage from their first fixated picture faster if it mismatches the target label, than in the case of a match.

Method

Participants were recruited from a database of parents who had previously expressed an interest in participating in developmental studies. In the week before visiting the laboratory, primary caregivers of all participants were sent the Oxford CDI (Hamilton, Plunkett, & Schafer, 2000), a British adaptation of the MacArthur-Bates CDI (Fenson *et al.*, 1994), normed on the local population. The Oxford CDI lists 416 words, and assesses both receptive and productive vocabulary. Parents brought their completed CDIs with them to the testing session. In a small number of cases, they completed the form on the day of testing, either during their visit, or returned by post shortly after. Toddlers who visited the laboratory were given a small gift for their participation.

Twenty 18-month-olds and twenty 24-month-olds participated in the study. Three failed to complete the study, and were removed from analysis. Total receptive CDI scores were checked against previously collated norms, and toddlers' comprehension of test items was assessed. Following preliminary checks, one further eighteen-month-old was removed from analysis for an extremely low receptive CDI score (in the 5th percentile of previously collected CDIs for 18-month-olds). The final sample included seventeen 18-month-olds (10 males, mean age: 18.3 months; range: 17.0 to 18.9 months), and nineteen 24-month-olds (13 males, mean age: 24.1 months; range: 23.3 to 24.9 months).

Selection of test items

To select age-appropriate words, 548 previously collected Oxford CDIs were consulted. The younger age (18 months) was used as a baseline for lexical comprehension rates. From the 179 CDIs which fell in the age range 17.5 to 18.5 months-of-age, concrete nouns reported as 'understood' by more than 50% of 18-month-olds were considered as potential stimuli. Normative word associations were collated from the Birkbeck Word Association Norms (Moss & Older, 1996), and 18 words were selected for use in the current study.

Stimulus preparation

Two stimulus lists were created, in which half of the items were named 'target' pictures, and half of the items were unnamed 'distracter' pictures. Pairs of pictures shared no taxonomic or associative relationship, and no phonological onset or rhyme (e.g., target: *fish*, distracter: *aeroplane*), and were yoked across lists. Items which acted as named targets in one list were unnamed distracters in the other list. Stimulus lists are given in the Appendix.

Audio stimuli were created in a single recording session, in a sound-attenuating booth on a Marantz solid state recorder sampling at 44.1 kHz. A minimum of three tokens of each auditory stimulus were produced by a female native speaker of British English, using high-affect, child-directed speech. The single best token of each stimulus was manually selected for clarity, typicality and affect, and edited to remove head and tail clicks. Visual stimuli were high quality digital photographs, judged as typical exemplars of test items by three native speakers of English. Pictures were presented on a 10% grey background.

Procedure

After a few minutes of 'settling in' in a dedicated play room, toddlers sat on their caregiver's lap facing a large flat-screen monitor in a purpose built IPL booth. Caregivers were asked to wear headphones and to close their eyes during the procedure, which lasted approximately one and a half minutes. The experimenter moved to an adjacent control room. After drawing the toddler's attention to the screen area using a 'ding' sound from a centrally located loudspeaker, each trial was manually initiated when the toddler's attention was centred on the screen. While the screen was blank, an auditory attention phrase began (e.g., *Ooh look!*) followed by an inter-stimulus interval (ISI) of 200 ms, then the target word in isolation (e.g., *Fish!*). 400 ms after the onset of the target word, the picture pair appeared. Pictures remained onscreen for 2,500 ms. Trial time-course is illustrated in Figure 2.
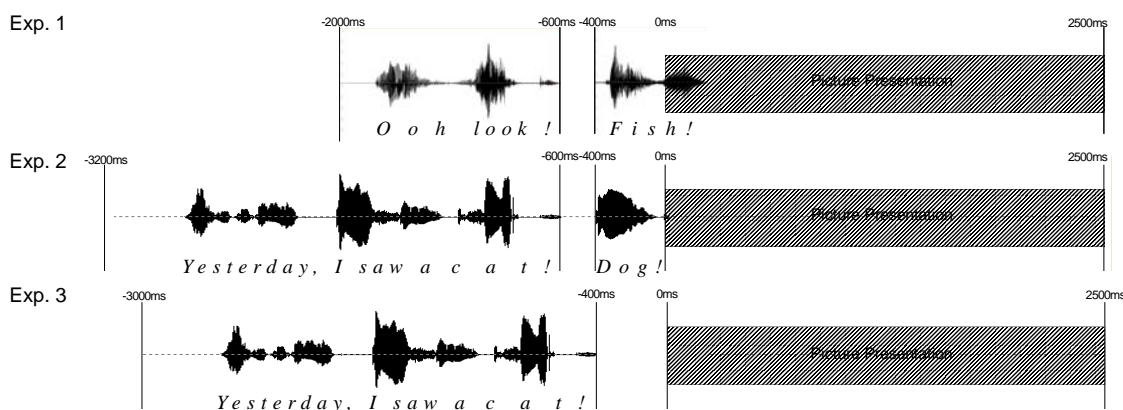
Exp. 1

-2000ms   -600ms -400ms   0ms   2500ms

Picture Presentation

O o h   l o o k !   *F i s h !*

Exp. 2

-3200ms   -600ms -400ms   0ms   2500ms

Picture Presentation

Y e s t e r d a y ,   I s a w   a   c   a   t !   *D o g !*

Exp. 3

-3000ms   -400ms   0ms   2500ms

Picture Presentation

Y e s t e r d a y ,   I s a w   a   c   a   t !

Figure 2. Trial timing in three experiments. 0ms indicates the onset of the test-phase of the trial. The mean duration of the target words in Experiment 1 was 729 ms (*SD* = 96), and in Experiment 2, 551ms (*SD* = 20ms), meaning that the majority of target labels continued after picture presentation had begun.

Each toddler saw 9 trials from a single stimulus list. Trial order was randomised on presentation. Target side was counterbalanced. Toddlers sat approximately 90 cm from the screen, with a display area 87 cm wide. Each picture was 34 cm wide. Together they occupied a visual angle of approximately 52º, separated by a gap of 17 cm (12º).

Scoring & Measures

Toddlers' eye movements were monitored by small cameras located above the two picture areas, and combined into a split-screen picture by a video mixer. Recordings were digitally captured during test. Blind manual coding was conducted offline, by an experienced coder, using frame-by-frame observations at a temporal accuracy of 40 ms. 10% of participants were re-coded by a second coder to ensure consistency (inter-coder reliability: $r(36)$ = 0.97, $p < 0.001$). Looks to the left and right picture areas of the screen were coded from the onset of the pictures. Both large- and small-scale timing measures were calculated: a macro-level measure assessed the relative preference for the named target picture over the course of the whole trial, and two micro-level measures assessed the direction and duration of the toddlers' first fixation.

Macro-level. The proportion of target looking (PTL) is the total amount of time spent looking at the target (T) as a proportion of the total amount of time spent looking at both pictures (T + D). It can be represented as T / (T + D). This measure represents relative picture interest over the whole picture presentation period (2,500 ms), excluding time spent switching between pictures, blinking, or looking away from the screen area.

Micro-level. The percentage of target-first fixations is calculated from the number of trials in which the first responsive fixation was to the target picture, out of all trials where anticipatory fixations had not occurred. The duration of the first fixation is a measure of reaction time which describes the amount of time taken to initiate a saccade away from the first fixated picture. In this words-before-pictures version of the IPL task, it is possible for toddlers to shift their gaze away from the centre of the screen prior to picture presentation. To ensure that fixations represent responses to the test stimuli, trials including anticipatory eye movements or external distractions are not included in analysis of micro-level measures.

The 'linking hypotheses' for using these measures are as follows: If toddlers distribute their fixations randomly between pictures for the duration of the trial, then relative measures assessing looking preference would even out across trials, creating means of similar value for target and distracter pictures. However, if the name of the picture induces a systematic visual preference for named targets over unnamed distracters, then the pattern of behaviour is consistent with toddlers mapping spoken words to the correct pictures. As argued by Aslin (1997), the duration of accumulated fixations is difficult to interpret (does more looking imply continuous interest, effortful processing, or blank staring?). For this reason, the micro-structure of the trial is also valuable, as the very first fixation following the appearance of a novel picture can serve as a measure of the ease and speed of semantic processing. Shorter first fixations to distracters than to targets would indicate how quickly toddlers are able to reject pictures mismatching the referent of the auditory label. Accuracy in the direction of the first fixation indicates how easily

they are able to recognise features of novel pictures presented parafoveally.

Data exclusions. Recent IPL research has demonstrated that parents can pick out which words their children will be able to identify in a standard picture-finding task. Despite historic concerns about the accuracy of parental comprehension reports (e.g., Tomasello & Mervis, 1994), recent research has shown that British parents are typically quite accurate in their assessment of comprehension. Styles and Plunkett (2009b) demonstrated that 18-month-olds showed the predicted preference for named items which their parent had marked as 'understood' in a vocabulary inventory, but not for words which remained unmarked. Differences between the design of this and previously reported tasks by Houston-Price, Mather and Sakkalou (2007), suggests that British parents are somewhat conservative in their judgements, and only mark words which will be identified in a relatively difficult task (i.e., a single presentation, paired with an easily confusable distracter from the same taxonomic category). As the primary interest here is about relationships between words which are integrated into the lexicon, a conservative exclusion criterion is employed: Only those trials in which the target word was reported as understood are included in analysis of eye movements.

In addition, trials in which toddlers fixated the left or the right picture area of the screen prior to picture presentation were excluded from analysis of first fixation measures. In analysis of reaction time, the visual inspection method described in detail by Canfield et al. (2007), was used to remove the small proportion of trials in which the first saccade was launched prior to the onset of visual stimuli (via expectation), or was landed abnormally late. This ensured that all fixation durations included in participant means were from trials in which looking behaviour was typical.

Results

The mean receptive CDI score for 18-month-olds was 191 words ($SD = 75$) out of a possible 416, and for 24-month-olds, 350 words ($SD = 57$). Eighteen-month-olds were reported to understand a mean of seven of the nine words used as targets in their list ($SD = 1.8$). Twenty-four-month-olds were reported to understand a mean of nine ($SD = 0.6$). Twenty-four-month-olds thus had larger receptive vocabularies (U (17, 19) = 20, $p < 0.001$), and knew more of the target labels (U (17, 19) = 65.5, $p < 0.001$).

The lexical exclusion criterion resulted in exclusion of 32 of the original 153 trials available for 18-month-olds (21%) and 8 of the original 171 trials available for 24-month-olds (5%). In a small number of

trials, infants looked away from the screen prior to the onset of pictures, or recorded screen fixations shorter than 120 ms. A further 8 trials (3%) remained unanalysed according to this criterion.

The proportion of target looking (PTL) is illustrated in Figure 3. Mean PTL for 18-month-olds was 0.56 ($SD = 0.11$), and 24-month-olds, 0.59 ($SD = 0.11$). Both age groups thus looked at the target significantly more than at the distracter (18m: $t(16) = 2.12$, $p = 0.05$, $d = 0.51$; 24m: $t(18) = 3.91$, $p < 0.01$, $d = 0.90$). This finding is consistent with the prediction that toddlers understood the target label, and correctly mapped it to the target picture. A two-way ANOVA of age group (18m, 24m) and stimulus list (list A, list B) revealed no main effects or interactions, indicating that lexical comprehension did not differ between participant groups or word lists.

For 18-month-olds, trials in which the first fixation was to the target constituted 47% ($SD = 24\%$) of all trials, and for 24-month-olds, 54% ($SD = 16\%$). The percentage of first fixations to the target did not differ significantly from chance, indicating that toddlers were equally likely to fixate either picture in their first look.

The average duration of first fixations is illustrated in Figure 4, according to whether the first fixated picture was the named target or the unnamed distracter. For 18-month-olds, the mean duration of target fixations was 1196 ms ($SD = 283$ ms), and distracter fixations, 858 ms ($SD = 381$ ms). For 24-month-olds, target fixations were 1094 ms ($SD = 382$ ms) and distracter fixations, 554 ms ($SD = 203$ ms). The speed of disengaging from a distracter was thus faster than the speed of disengaging from a target for both age groups (18m: $t(25) = 2.6$, $p < 0.05$, $d = 1.06$; 24m: adjusted $t(25.8) = 25.8$,
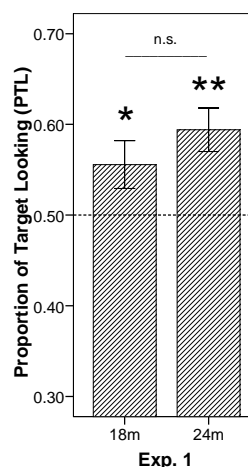
Figure 3. Proportion of target looking (PTL) according to age group in Experiment 1. +/- one standard error. Single sample t-tests compare PTL to the chance value of .5. * p < 0.05. ** p < 0.01.

$p < 0.01$, $d = 1.81$). This finding is consistent with the prediction that reaction time indexes comprehension of the target word, as infants in both age groups looked away from pictures which mismatched the unfolding auditory label faster than they looked away from pictures which matched.

When comparing reaction time across age groups, 24-month-olds were significantly faster to disengage from distracters than 18-month-olds (adjusted $t(15.2) = 2.53$, $p < 0.05$, $d = 1.30$). No significant age difference was evident in the speed of disengaging from targets. This finding shows an age-related improvement in the speed of rejecting a mismatching distracter picture, while named targets remained equally engaging.

Discussion

This study demonstrates that toddlers at 18 and 24 months-of-age showed behaviour consistent with recognition of known words in a fast-paced free-looking task, where the target label began shortly before the pictures appeared on screen. As illustrated in Figure 1A, hearing the target label activated an internal representation sufficiently detailed to facilitate recognition of a target picture which appeared on the screen after the target word had begun. Named targets accumulated more looking time than unnamed distracters, and the first fixated picture was disengaged from faster when it mismatched the target label than when it matched.

Novel features of the task have now been validated: Lexical access of the target word was not impaired by the onset of visual stimuli; the trial was sufficiently long for toddlers in both age groups to accumulate a preference for the named target; and the
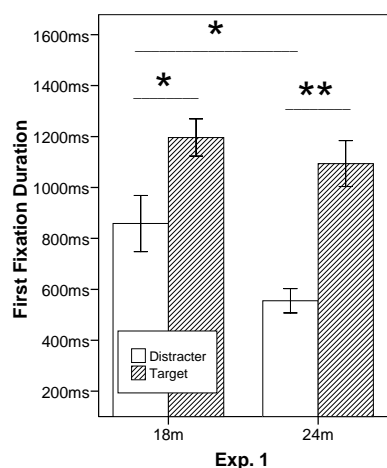

Figure 4. Duration of first fixation according to age group and look direction in Experiment 1. +/- one standard error. * p < 0.05. ** p < 0.01. Comparisons marked above a pair of bars indicates an independent samples t-test comparing responses to target and distracter pictures. The comparison at the top of the plot indicates a difference between age groups, for distracter fixations only.

SOA of 400 ms between the target word and the onset of the pictures allowed target recognition. In addition, the measures used were sufficiently sensitive for a 'one-shot' task, in which toddlers were exposed to each stimulus only once.

The finding of speeded distracter rejection parallels earlier toddler eye-gaze studies investigating reaction time (e.g., Fernald, Pinto, Weinberg, & McRoberts, 1998; Swingley & Fernald, 2002) or 'latency' (e.g., Mani & Plunkett, 2007) to switch from mismatching pictures following the onset of a word. Indeed, the increase in the speed of distracter rejection between 18- and 24-month-olds' distracter fixations mirrors developmental improvements in lexical processing speed reported in picture-first looking tasks (Fernald et al., 1998). The finding of target identification for both age groups acts as a behavioural baseline against which primed adaptations of the task can be compared.

Experiment 2

The previous experiment demonstrated that 18- and 24-month-olds are able to identify named pictures in a free looking task where the target word preceded picture presentation. Two features of the task piloted in Experiment 1 are critical for an IPL implementation of sequential auditory priming. Firstly, the words-before-pictures stimulus organisation means that both the prime and the target words can be presented prior to the onset of the pictures, prior to any interference from the visual domain. Secondly, presenting each stimulus only once avoids the possibility of teaching novel associations between items, or inducing memory effects. This is particularly important in a population where participants' vocabulary size and attention span precludes 'padding' repetitions with large numbers of intervening trials.

In adapting this free-looking task to a priming context, Experiment 2 retains the trial timing of Experiment 1, but replaces the auditory attention phrase with a priming phrase. In half of the trials the prime and the target are taxonomically and associatively related, in half they are not. Given that the priming task will include two conditions per participant, the number of trials is increased from nine to twelve.

If the toddler lexicon is interconnected in an adult-like way, hearing a prime would be expected to affect the ease and speed of lexical access for related words either through overlapping representations, or via the flow of activation between discrete but interconnected representations (cf. Figure 1B). Toddlers' lexical access, as indexed by eye movements, would be

expected to be enhanced in the related prime condition, relative to the unrelated prime condition.

Method

Thirty six 18-month-olds and thirty six 24-month-olds participated in the study. Following preliminary checks of receptive CDI scores, two eighteen-month-olds were removed from analysis for extremely low vocabularies (in the 5th percentile of previously collected CDIs for 18-month-olds), and one, when it was observed that they contributed valid trials to only one priming condition. In the final sample, 33 18-month-olds (15 males; mean age: 18.1 months; range: 17.5 to 18.8) and 35 24-month-olds (14 males; mean age: 24.0 months; range: 23.4 to 25.0) were available for analysis.

Materials

Auditory and visual stimuli were selected and prepared as in the previous experiment using a DAT recorder sampling at 44.1 kHz. Two stimulus lists were created in which twelve words acted as auditory 'primes' and twelve words acted as auditory 'targets'. Each of the twelve target pictures appeared on screen alongside one of the twelve unnamed 'distracters' during the test phase of the trial. Picture pairs were yoked across lists. The two stimulus lists are given in the Appendix.

Across lists, each target occurred with two different primes, a 'related' prime in one list and an 'unrelated' prime in the other. Related word-pairs had an attested forward association in adult British English (Moss & Older, 1996) and were basic-level taxonomic sisters (e.g., prime: *cat*; target: *dog*). The decision to include both association and taxonomy was made on the basis of the 'associative boost' evident when the relationships of taxonomy and association are combined in adult priming (Moss, Ostrin & Tyler, 1997). Unrelated word-pairs shared no semantic or associative relationship, and no phonological onset or rhyme (e.g., prime: *plate*; target: *dog*). Similarly, distracters shared no phonological, semantic or associative relationship with prime or target (e.g., distracter: *boat*). Within a list, half of the primes were related and half unrelated, and no stimulus was repeated.

In the primed procedure, words acting as 'targets' were labelled for all participants, and never appeared as unnamed distracters. Given that inherent differences in the visual interest of pictures used as target and as distracters could confound straightforward assessment of target preference, analysis is therefore limited to the effect of the auditory priming condition.

For each participant, priming was calculated as the difference between the related and the unrelated priming condition.

Procedure

The procedure was the same as in the previous experiment, with the exception that infants were tested in an adjacent booth, facing a rear-projection screen. Pictures were 32 cm wide. Together they occupied a visual angle of approximately 48°, separated by a gap of 15 cm (10°).

While the screen was blank, the priming phrase began (e.g., *Yesterday, I saw a cat!*), followed by an inter-stimulus interval (ISI) of 200 ms, then the target word in isolation (e.g., *Dog!*). A short prime-to-target ISI was employed to capture the early stages of automatic activation. Moss, Ostrin, Tyler & Marslen-Wilson's (1995) ISI of 200ms was selected, on the grounds that toddlers' phonological processing speed is similar to adults' (Swingley, Pinto, & Fernald, 1999). To reduce potential sources of interference, no attention device appeared on the screen during the priming phase of the trial. The 400 ms SOA and 2500ms picture duration were identical to Experiment 1, as illustrated in Figure 2. Each toddler saw 12 trials from a single stimulus list. Half of the infants saw list A, and half, list B. Trial order was randomised on presentation, and target side was counterbalanced within and between lists.

Results

The mean receptive CDI score for 18-month-olds was 181 words ($SD = 64$), and for 24-month-olds, 317 words ($SD = 62$). Eighteen-month-olds were reported to understand a mean of nine of the twelve prime words ($SD = 2.7$) and nine of the twelve target words ($SD = 2.3$), 24-month-olds, eleven primes ($SD = 1.5$) and eleven targets ($SD = 1.4$). Twenty-four-month-olds' receptive vocabularies were thus significantly larger than 18-month-olds' ($U(33, 35) = 79.5$, $p < 0.001$), and they knew significantly more test items than 18-month-olds ($U(33, 35) = 172.5$, $p < 0.001$).

Only trials in which both the prime and the target were reported as understood were included in analysis of priming. According to this criterion, 242 of the original 396 trials were available for analysis (61%) for 18-month-olds, and 378 of the original 420 of trials (90%), for 24-month-olds. A further 27 trials (4%) were unanalysed as they contained no fixations longer than 120ms.
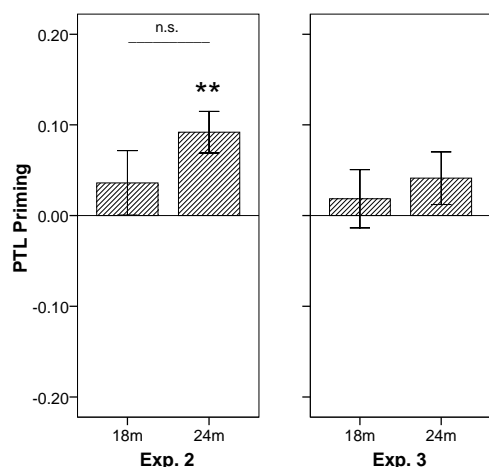
Figure 5. Priming effect for PTL (Related prime minus unrelated prime), in two experiments. Single sample t-test compares priming in each age group to the chance value of 0ms. Independent samples t-test compares priming in the two age groups. +/- one standard error. ** p < 0.01.

The mean PTL in each priming condition was calculated for each toddler. Priming, calculated as the difference between PTL for related and unrelated trials, is illustrated in Figure 5. Mean priming for 18-month-olds was 0.04 ($SD = 0.18$), and for 24-month-olds, 0.09 ($SD = 0.13$). For 24-month-olds, priming was significantly above chance ($t (32) = 4.0$, $p < 0.001$, $d = 0.70$). In a two-way ANOVA of age group (18m, 24m) and list (list A, list B), there was a main effect of age ($F(1,55) = 4.83$, $p < 0.05$, partial $\eta^2 = 0.08$) indicating that the priming effect was larger for the older age group, although the difference did not achieve significance in an independent-samples t-test. A main effect of list was also observed ($F(1,55) = 22.63$, $p < 0.001$, partial $\eta^2 = 0.29$), indicating that priming was larger for one list of words than the other. No significant interaction was evident.

In 468 trials (78%), toddlers had not fixated either of the picture areas of the screen by the time the pictures were presented. 58% of first fixations were to the target for 18-month-olds and 59%, for 24-month-olds. A three-way repeated measures ANOVA compared the influence of priming condition (related, unrelated), age group (18m, 24m) and stimulus list (list A, list B) on the accuracy of the first fixation. There was a main effect of prime condition ($F(1, 58) = 5.735$, $p < 0.05$, partial $\eta^2 = 0.09$), with no further effects or interactions. Paired sample t-tests clarified that the proportion of first fixations to targets was greater in the related prime condition (related: $M = 65\%$ ($SD = 27\%$); unrelated: $M = 53\%$ ($SD = 30\%$); $t(61) = 2.23$, $p < 0.05$, $d = 0.35$). This finding indicates that the priming condition influenced processing prior to landing the first fixation.

The mean duration of first fixations to targets and distracters was calculated separately for trials from each of the priming conditions. When toddlers' first fixation was to the target, fixation priming was calculated as the difference between the duration of target-first fixations in the two priming conditions. The magnitude of target fixation priming was 38ms ($SD = 615$ ms) for 18-month-olds and 40ms ($SD = 389$ ms) for 24-month-olds. A two-way ANOVA comparing the influence of age group (18m, 24m) and list (list A, list B) on target fixation priming revealed no significant main effects or interactions. Target fixation priming (pooled across groups) was not significantly greater than 0 ms.

Distracter fixation priming, illustrated in Figure 6, was calculated as the difference between the duration of fixations in the two priming conditions. The magnitude of distracter fixation priming was 218 ms ($SD = 553$ ms) for 18-month-olds, and 123 ms ($SD = 348$ ms) for 24-month-olds. A two-way ANOVA comparing the influence of age group (18m, 24m) and list (list A, list B) on distracter fixation priming also revealed no significant main effects or interactions. Distracter fixation priming (pooled across groups) tended toward significance, ($t(25) = 0.18$, p=0.06, $d = 0.04$). These findings show that while the duration of the target fixation was unaffected by the priming condition, primed word pairs tended to facilitate the rejection of mismatching pictures.

Discussion

Having demonstrated in Experiment 1 that toddlers at 18 and 24 months-of-age can identify target pictures in the fast-paced words-before-pictures task, and that two measures index comprehension of the named targets, the primary goal of this study was to investigate whether relationships *between words* influence the pattern of target looking. Novel features of the priming task included the use of auditory primes prior to target labels (ISI = 200ms), in a words-before-pictures stimulus arrangement. A combination of taxonomy and association was selected to boost any priming effects observed.

As predicted, looking behaviour was affected at both the macro-level and the micro-level of analysis. For older toddlers, there was greater interest in the target in the related condition (PTL). The age groups tended to differ, with older infants showing a greater priming effect. The prime tended to influence reaction time (albeit not significantly). This reaction-time trend did not differ between age groups, and suggested that toddlers in both age groups might be faster to disengage from unnamed distracters in the related prime condition. In addition, toddlers in both age groups showed an increase in the percentage of first fixations to targets in the related
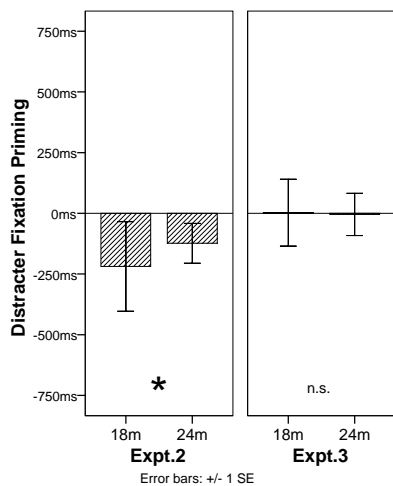
Figure 6. Priming effect for duration of first fixation, in two experiments. Single sample t-test compares priming (pooled across age group) to the chance value of 0ms. +/- one standard error. * p< 0.05. Comparison indicates pooled value.

prime condition. Comparing this finding with the results from the previous experiment, toddlers in both age groups showed enhanced target recognition in the percentage of target-first trials when a related word preceded the target label, compared to when the target label occurred alone. This finding is especially interesting given that toddlers had not previously seen the test pictures, and did not know which picture would occur in which location.

In both age groups, the higher percentage of target-first trials and the tendency towards faster distracter rejection suggests faster lexical access of the target word due to pre-activation. In addition, for older toddlers, the effect of priming condition on PTL is consistent with more and longer-lasting activation of the target representation. However, the locus of the priming effect remains unclear. In order to assess whether the prime word alone was responsible for the priming effect, or whether the prime word influences picture looking via its influence on the target word, a third experiment was conducted.

Experiment 3

The previous experiment demonstrated a clear effect of the lexical prime on referent identification. The findings were consistent with both word-to-word 'lexical' priming or concept-to-picture 'semantic' priming, or some combination of the two (cf., Fig. 1.2). Removal of the target label (cf., Fig. 1.3) allows these two possibilities to be teased apart to some degree: If the prime alone triggers target preference in the absence of the target label, it would suggest that the internal representation of 'cat' is sufficiently similar to the

internal representation of the word 'dog' to trigger some form of 'best-match' between the spoken word and the picture; If toddlers' looking is unsystematic, with both unlabelled pictures rejected as equally bad matches to the prime word, it would suggest that the prime word influences looking at the target picture only via enhanced activation of the target word.

Method

Thirty six 18-month-olds and thirty six 24-month-olds participated in the study. Following preliminary checks of receptive CDI scores, three additional18-month-olds and one 24-month-old were removed from analysis when it was observed that they contributed analyzable trials to only one priming condition. In the final sample, 32 18-month-olds (14 males; mean age: 18.3 months; range: 17.7 to 18.8) and 35 24-month-olds (18 males; mean age: 24.3 months; range: 23.5 to 24.9) were available for analysis.

The stimuli were identical to Experiment 2, with the exception that all target labels were omitted. The inter-stimulus interval between the offset of the prime and the onset of the pictures was also shortened slightly, to avoid a prolonged silence. Timing is illustrated in Figure 2. Apart from these changes, the procedure was the same as previously described.

Results

The mean receptive CDI score for 18-month-olds was 260 words ($SD = 76$), and for 24-month-olds, 356 words ($SD = 52$). Eighteen-month-olds were reported to understand a mean of ten of the twelve prime words ($SD = 1.6$) and eleven of the twelve target words ($SD = 1.0$), 24-month-olds, twelve primes ($SD = 1.3$) and twelve targets ($SD = 0.7$). Twenty-four-month-olds' receptive vocabularies were thus significantly larger than 18-month-olds' ($U (32, 33) = 689.5$, $p < 0.001$), and they knew significantly more test items than 18-month-olds ($U (32, 33) = 753.0$, $p < 0.001$). For two 24-month-olds, where CDI data were unavailable, the median score for each item in their age group was used for lexical exclusion.

According to the lexical exclusion criterion employed in the previous study, 306 of the original 374 trials (80%) were available for analysis for 18-month-olds, and 396 of the original 419 trials (95%) were available for 24-month-olds. A further 27 trials (4%) of trials remained unanalysed as they contained no fixations longer than 120ms.

Mean PTL in each priming condition was calculated for each toddler. Priming is illustrated in Figure 5. Mean priming for 18-month-olds was 0.02 ($SD = 0.18$), and for 24-month-olds, 0.04 ($SD = 0.17$). A two way ANOVA comparing age group (18m, 24m) and

list (list A, list B) revealed a significant main effect of list ($F(1, 63) = 47.7$, $p < 0.001$, partial $\eta^2 = 0.43$), indicating that priming was larger for participants who saw one set of stimuli than for participants who saw the other. There was no significant main effect of age, nor interaction, and priming did not significantly differ from zero for either age group.

In 517 trials (77%), toddlers had not fixated either of the picture areas of the screen by the time the pictures were presented. 53% of first fixations were to the target for 18-month-olds and 56%, for 24-month-olds. A three-way repeated measures ANOVA comparing the influence of priming condition (related, unrelated), age group (18m, 24m), and stimulus list (list A, list B) revealed no main effects or interactions. The percentage of first fixations to target did not differ from chance, a finding differing notably from the findings of the previous experiment.

The mean duration of first fixations to targets and first fixations to distracters was calculated separately for trials from each of the priming conditions. The magnitude of target fixation priming was 4 ms ($SD = 583$ ms) for 18-month-olds and 60 ms ($SD = 751$ ms) for 24-month-olds. A two-way ANOVA comparing the influence of age group (18m, 24m) and list (list A, list B) on target fixation priming revealed no significant main effects or interactions and target fixation priming (pooled) did not differ from chance. The magnitude of distracter fixation priming was 179 ms ($SD = 784$ ms) for 18-month-olds and 6 ms ($SD = 632$ ms) for 24-month-olds. A two-way ANOVA comparing the influence of age group (18m, 24m) and list (list A, list B) on distracter fixation priming revealed no significant main effects or interactions and distracter fixation priming (pooled) did not differ from chance. Thus, in the absence of an explicit target label, distracter pictures were rejected equally fast regardless of whether the picture was related to the auditory prime.

Discussion

The purpose of Experiment 3 was to establish whether the prime generated interest in the target picture via similar conceptual representations in the infant semantic system. Overlapping representations could result from shared abstract semantic features like 'is an animal', 'lives in a house', or from similarities between an internally generated image of the prime and the visual form of the target. By using the same stimuli as the previous experiment, but omitting the target label, it was possible to assess whether the effect of the prime was mediated by activation of the target word. The relationship between the auditory prime word and the unnamed target picture was not found to influence

looking behaviour in macro-level measures of target preference, nor in micro-level measures of first fixation direction and duration.

Given the well-documented cases of overextension in (e.g., Bowerman, 1987; E. Clark, 1973) and theoretical predictions about semantic feature overlap (c.f., Hills et al., 2009), it is somewhat surprising that performance in the priming task differed so dramatically with the omission of target labels. However, these results indicate that toddlers in both age groups were not willing to accept a picture of a dog as a referent of the word 'cat' when they understood both words: They judged related targets and unrelated distracters to be equally uninteresting in the absence of the target label. This finding also sheds light on the nature of the priming effect observed in Experiment 2, an issue to which we will return in the General Discussion.

As Experiment 3 demonstrated no difference between priming conditions, interpretation of the null result should be treated with some degree of caution. For example, the prime-to-pictures ISI of 400ms may have been too short for a fully featured activation of the prime word to exhibit overlap with the target picture. Conversely, this ISI may have been too long to observe the influence of a short-lived feature-based overlap. Future studies will therefore be needed to clarify the time course of activation of different kinds of semantic relationship.

General Discussion

This series of studies was designed to address two main questions: Are adult-like semantic relationships between words/concepts evident in toddlers' behavioural responses to spoken language? And if so, where does the locus of the priming effect reside? Priming effects were observed for toddlers in both age groups, and the observed effects were consistent with a model of semantic organisation in which related words have interlinked representations between which activation can 'flow' during online language processing.

The primed IPL task was designed to mimic adult sequential priming tasks in a toddler-friendly context, by replacing lexical decision with a period of free-looking. The first experiment piloted an adaptation of a traditional free-looking task for infants, in which the auditory target label began shortly before the onset of the picture pair, allowing the unfolding target word to begin prior to any disruption from the visual domain. Toddlers in both age groups demonstrated the ability to identify the referents of named pictures in both micro- and macro-level measures of eye-gaze. Features of this

design which are novel in toddler language research include the task's fast pace, lack of repetition, and use of reaction time measures in a words-before-pictures scenario. Given the high speed of stimulus presentation, it is noteworthy that toddlers at both ages demonstrated reliable target identification in both macro- and micro-level measurements. This indicates that the current task and the measures employed are effective indices of lexical comprehension, even though the label was presented prior to the onset of the previously unseen pictures.

In the second experiment, the auditory attention phrase was replaced with a priming phrase, concluding in a related word half of the time. Both age groups showed an improvement of almost 10% in the accuracy of the first fixation, and were more than 100ms faster to reject unnamed distracters, in the related prime condition, compared to the unrelated prime condition. For the older age group, a difference of almost 10% was also observed in overall target preference in the related prime condition. These findings demonstrate that the current design was sufficiently sensitive to capture differences in the ease and speed of lexical comprehension brought about by relationships between items integrated into the toddler lexicon. The third experiment, in which the target label was omitted, clarified that the priming effect observed in Experiment 2 was produced by sequential activation of related prime and target words. When the prime alone was heard, it did not produce sufficient activation of the target concept to facilitate target preference or above chance accuracy in the direction of the first glance – even though the timing of the prime word was consistent in both primed experiments.

It is interesting to note how these findings relate to data collected from implicit processing tasks, such as toddler ERP studies. Torkildsen and colleagues (2007) report toddlers' sensitivity to semantic relationships between sequential auditory word-pairs, when assessing the 'N400 component'. Our results suggest that this component does indeed have a cognitive outcome, as sequential activation of related words influences looking behaviour in this age range.

Fast Pace. The fast-paced design included a relatively short period of free looking time (2,500ms) which was expected to eliminate strategic responding, by giving toddlers little time to inspect both pictures. The finding of reliable target discrimination in both age groups (Experiment 1) demonstrated that only a short amount of time is required for toddlers to show lexical comprehension, using measures of fixation accuracy, fixation duration, and accumulated picture preference.

New Measures. The words-before-pictures stimulus arrangement in this experiment necessitated the introduction of novel reaction time measures. In standard toddler free-looking tasks, an auditory 'decision point' during ongoing picture display becomes a reference point for measurements of 'latency' (e.g., Mani & Plunkett, 2007) or RT to switch from a distracter (e.g., Fernald et al., 1998). In the primed IPL task, toddlers heard the start of the target word before they knew which side the target would be located. The direction and duration of the first fixation was expected to index toddlers' responses to whether or not the first fixated picture matched the unfolding acoustic label. The measure of first fixation duration was sensitive to target discrimination, and yielded priming effects in both age groups. The measure of first fixation direction was not sensitive to general target discrimination, but was boosted by a related prime when the target was labelled.

Developmental Trajectory and Automaticity. In the micro-level measurements concerning the first fixation in the trial, toddlers in both age groups demonstrated priming effects. These priming effects occurred quite fast, and influenced behaviour at the onset of the trial. In the macro-level measure concerning accumulated fixations over the course of the whole trial, on the other hand, only older toddlers showed priming effects. This finding suggests that the accumulated fixations may be the outcome of a more-advanced 'strategic' looking behaviour, which arises out of developments in short-term memory, or in interpreting the nature of the 'game'. The measures of fist fixation direction and duration, by contrast, appear to be more automatic, as they are acquired earlier, and have their effect earlier than the measure of general target preference. These contrasting measures could prove to be useful in future investigations of automatic versus strategic priming effects.

Primed Facilitation or Inhibition. All sequential priming effects can be characterised as facilitation from a related prime *enhancing* lexical access, or as interference in the lexicon from an unrelated prime *inhibiting* lexical access. The priming effect observed in the macro-level measure could arise out of either process. For example, hearing 'cat' might make recognition of the word 'dog' easier than usual. Alternatively, hearing 'plate' before 'dog' might confuse toddlers, making recognition of 'dog' more difficult than usual. While the measure of primed target preference is consistent with either account, the finding of above-chance first-fixation accuracy *only* in the case where the prime is related and the target named, strongly suggests facilitation of lexical comprehension. However, given that the comparison of label-only and prime-plus-label

occurs between subject groups (Experiment 1 and Experiment 2), it is possible that individual differences may have contributed. Further studies are needed to clarify whether this facilitation account is also valid within the same group of participants.

Stimulus Controls. Two stimulus controls were considered critical for primed IPL. First, in order to avoid inadvertent memory effects which might interfere with priming, no stimuli were repeated within a testing session. Secondly, and perhaps most importantly, only those trials in which toddlers were reported to understand both the prime and the target were included in the analysis. This is an important control for studies attempting to establish the organisation of the developing lexicon. From an experimental perspective, the inclusion of unknown words generates a pattern of noise which is likely to mask genuine priming effects: If a prime or a target is not understood in a 'related' trial, that trial effectively becomes 'unrelated,' as only one word shares a relationship with the named target. Yet if a prime in an 'unrelated' trial is not understood, the trial remains 'unrelated' (with one word sharing a relationship with the target). This skew reduces the difference between the two trial types, potentially masking legitimate priming effects.

Eliminating this confound is particularly relevant for toddlers with small vocabularies, for whom this noise would be greatest. Pre-testing of items (e.g., in a standard IPL task) could have provided data about each toddler's comprehension, but would have confounded the stipulation of non-repetition. Instead, lexical comprehension of test items was assessed via parental report. Despite valid concerns about the voracity of parental report of comprehension (Tomasello & Mervis, 1994), recent research has demonstrated that parental report can reliably predict items which will attract lexical comprehension in IPL tasks at 18-months-of-age (Styles & Plunkett, 2009b).

Association and Taxonomy. In stimulus preparation, we maximised the likelihood of an associative 'boost' (Moss et al., 1995) by selecting related prime-target pairs which shared both semantic and associative relationships. It was interesting to note that many taxonomic sisters in the pool of potential test items also exhibited normative word association. Given the small size of the toddler lexicon in the second year, the common combination of association with taxonomy may be a salient property of the developing lexicon, and is a pattern which fits well with the computational modelling of Steyvers and Tenenbaum (2005). However, to tease apart which of these two kinds of relationship is more important for sequential activation in the lexicon, further investigations are needed to establish which, of

taxonomy and association, is the greater source of organisation in toddlers' knowledge structures.

List Effects. In Experiment 2 and 3, main effects of 'list' were detected in the primed measures of PTL, indicating that toddlers who saw one stimulus list showed a greater priming effect than toddlers in the other. Interpretation of list effects is difficult, because it is not possible to separate variance generated by different groups of participants from variance generated by physically different test items (H. H. Clark, 1973). However, as the list effect was systematic across two different populations of toddlers (Experiment 2 and Experiment 3), it is likely to arise out differences between test stimuli. It might be expected that toddlers who saw the items in the list with stronger associations would show greater priming. However, toddlers who saw stimulus list B (with weaker associations) showed stronger priming than toddlers who saw list A. Further investigation revealed that differences in the visual interest of distracter pictures were the most likely cause: Related targets in list A had to compete with distracter pictures depicting animals (lion, chicken), vehicles (boat, pushchair) and food (toast, cheese), whereas related trials in list B had animals (monkey, bear) and clothing (sock, trousers), and inanimate household objects (bowl, table) for competition. Toddlers who saw list B were better able to demonstrate enhanced target recognition, as the distracters were less distracting.

Raajmakers and colleagues (Raajmakers, 2003; Raajmakers, Schrijnemakers, & Gremmen, 1999), argue that where list effects do not interact with priming, then the priming can be considered statistically robust. In the current series of experiments, no list effects were observed in the direction or duration of the first fixation, making these measures less sensitive to stimulus variation than the macro-level measure. This pattern further supports the interpretation that macro-level measures involve more strategic responses than micro-level measures of eye gaze. The micro-level measures were those in which priming effects were observed for both age groups, and which indexed high-speed responses to the sequential auditory stimuli.

Conclusions

Toddlers in their second year discriminated named target pictures from unnamed distracter pictures in a fast-paced looking task following sequential auditory word processing. Target identification was influenced by the combination of words heard prior to picture presentation. Target detection was enhanced when the label was preceded by a related word, compared to an unrelated word. This contrast demonstrates adult-like organisation in toddlers'

semantic system affecting the ease and speed of their lexico-semantic processing. This primed pattern of responding is consistent with a model of a developing lexicon in which sequential activation influences online language processing. The failure of the isolated prime word to influence target detection in the absence of the target label indicates that the priming effect is driven by relationships between words in the early lexicon. It remains to be seen whether one type of relationship (associative or taxonomic) provides organisational structure, or whether an adult-like mix of structures is encoded. Nonetheless, these findings demonstrate that priming effects can be observed in the online language processing of toddlers in the second half of the second year, and establishes stimulus arrangements and timing intervals for further investigation of the developing semantic system.

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Appendix

Stimulus Lists Experiment 1.

List A

Attention phrase[a]	Target	Distracter
Hey Wow!	Book	Juice
Ooh look!	Baby	Phone
Look at this!	Fish	Aeroplane
Hey Wow!	Key	Milk
Ooh look!	Bath	Flower
Look at this!	Toast	Bin
Hey Wow!	Teddy	Frog
Ooh look!	TV	Butterfly
Look at this!	Monkey	Brush

List B

Attention phrase[a]	Target	Distracter
Ooh look!	Juice	Book
Look at this!	Phone	Baby
Hey Wow!	Aeroplane	Fish
Ooh look!	Milk	Key
Look at this!	Flower	Bath
Hey Wow!	Bin	Toast
Ooh look!	Frog	Teddy
Look at this!	Butterfly	TV
Hey Wow!	Brush	Monkey

[a] Attention phrases counterbalanced through presentations using Latin Square order.

Stimulus Lists Experiments 2-3

List A

Prime & Carrier	Target	Distracter	Prime Type	WA-Strength[a]
Yesterday, I saw a cat	Dog	Boat	Related	66.7
Yesterday, I saw a sheep	Cow	Toast	Related	13.3
Yesterday, I ate an apple	Banana	Lion	Related	2.4
Yesterday, I bought a boot	Shoe	Cheese	Related	30.0
Yesterday, I bought a plate	Cup	Pushchair	Related	25.2
Yesterday, I bought a cot	Bed	Chicken	Related	9.5
Yesterday, I saw a train	Horse	Sock	Unrelated	0
Yesterday, I saw a lorry	Mouse	Table	Unrelated	0
Yesterday, I saw an elephant	Cake	Trousers	Unrelated	0
Yesterday, I bought a hat	Bus	Monkey	Unrelated	0
Yesterday, I saw a pig	Car	Bowl	Unrelated	0
Yesterday, I ate a biscuit	Coat	Bear	Unrelated	0

List B

Prime & Carrier	Target	Distracter	Prime Type	WA-Strength[a]
Yesterday, I bought a plate	Dog	Boat	Unrelated	0
Yesterday, I bought a boot	Cow	Toast	Unrelated	0
Yesterday, I bought a cot	Banana	Lion	Unrelated	0
Yesterday, I saw a cat	Shoe	Cheese	Unrelated	0
Yesterday, I bought a sheep	Cup	Pushchair	Unrelated	0
Yesterday, I ate an apple	Bed	Chicken	Unrelated	0
Yesterday, I saw a pig	Horse	Sock	Related	2.1
Yesterday, I saw an elephant	Mouse	Table	Related	8.9
Yesterday, I ate a biscuit	Cake	Trousers	Related	4.8
Yesterday, I saw a train	Bus	Monkey	Related	6.2
Yesterday, I saw a lorry	Car	Bowl	Related	4.8
Yesterday, I bought a hat	Coat	Bear	Related	12.5

[a] Forward Adult Word Association norms from Moss & Older