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What's in a link: Associative and taxonomic priming effects in the infant lexicon

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ABSTRACT

Infants develop a lexical-semantic system of associatively and semantically related words by the end of the second year of life. However, the precise nature of the lexical relationships that underpin the structure-building process remains under-determined. We compare two types of lexical-semantic relationship, associative and taxonomic, using a lexical-priming adaption of the intermodal preferential looking task with 21- and 24-month-olds. Prime-target word pairs were either associatively or taxonomically related or unrelated. A further control condition evaluated the facility of a prime word, in the absence of a target word, to promote target preferences. Twenty-four-month-olds, but not 21-month-old infants, exhibited a priming effect in both associative and taxonomic conditions, pointing to the formation of a lexical-semantic network driven by both associative and taxonomic relatedness late in the second year. The pattern of priming in 24-month-olds indicates the operation of inhibitory processes: unrelated primes interfere with target recognition whereas related primes do not. We argue that taxonomic and associative relationships between words are integral to the emergence of a structured lexicon and discuss the importance of inhibitory mechanisms in shaping early lexical-semantic memory.

1. Introduction

A proper understanding of how children acquire the meaning of words involves not only an appreciation of the concepts to which words refer but also how these concepts relate to each other. If children's early lexicons are best characterised as independent listings of words and their associated concepts, then an important part of any theory of lexical development will involve an explanation of how children make a qualitative shift to the network-like organisation that characterises the adult's lexical-semantic system. If, on the other hand, children's early lexicons are already organised in a network-like fashion, then a theory of how new words are added to the system and a set of principles that specify the structure of the system is required.

Many studies of early lexical development have successfully identified the range of words that young children can understand and say (Barrett, Harris, & Chasin, 1991; Dale & Fenson, 1993; Golinkoff, Mervis, & Hirsch-Pasek, 1994; Reznick & Goldfield, 1992), specified the constraints that they use to identify the referents of words (Markman, 1990, 1994) and established the conditions under which they learn novel words (Booth, Waxman, & Huang, 2005; Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006; Smith & Yu, 2008). Some researchers have argued that early word meanings are initially represented independently of each other (Anglin, 1970; Arias-Trejo & Plunkett, 2009; McNeill, 1970). For example, infants may be insensitive to the similarity in meaning of the words 'cat' and 'dog', even though both words may be initially used and understood correctly.

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Studies of older children have attempted to identify *when* words are integrated into a coherent semantic system. Anglin (1970) suggested that this process does not start until relatively late in development, at around 6–8 years. However, Mansfield (1977) tested children with a "false recognition" technique in which they were asked if a probe word had occurred in an immediately preceding sentence. She found that even 5-year-olds were more likely to make false recognition errors for semantically related than unrelated probe words. Mansfield concluded that 5-year-olds (the youngest children she tested) "have well-organized conceptual systems based on shared meaning components" (p. 57), indicating that lexical memory is semantically structured for these children.

Bowerman (1978) conducted a detailed analysis of spontaneous speech errors produced by her two daughters. As early as 2–4 years of age, the children occasionally substituted an intended word with one that was semantically related to it, even though the intended and substituted words had been used correctly for a substantial period. Bowerman (1978) concluded that "children's errors, like those of adults, can be interpreted as resulting from an incorrect choice among semantically related words that compete for selection in a particular speech context" (p. 979). Bowerman noted that these semantic substitutions were taken primarily from the category of verbs.

Based on evidence from free- and cued-recall tasks with pre-schoolers, Nelson and colleagues (Lucariello & Nelson, 1985; Nelson, 1985) have argued that intra-word relationships are initially formed on the basis of the event structures to which the words refer. For example, *eggs* and *cereal* might be related in the 3–4 year-old's lexical memory because they commonly occur at breakfast time. Nelson argues that this overlapping *function* predominates over more abstract, taxonomic relationships, such as *toast* and *ice-cream*, in structuring lexical memory during early childhood. In a similar vein, Petrey (1977) offers a re-analysis of Entwisle's (1966) study of childhood word associations and concludes that an episodic (thematic) to semantic shift in the system of lexical storage occurs between childhood and adulthood.

The view that episodic and functional factors constitute the core principles for the organisation of early lexical memory has not gone unchallenged. Blewitt and Toppino (1991) report a cued-recall task with 3- to 7-year olds and find no evidence of a shift from a schematic/functional/episodic to a taxonomic/semantic organisation of lexical memory over the age-range studied, and conclude that their "findings are consistent with the view that lexical memory is both schematically and taxonomically organized from early childhood" (p. 296). Waxman and Namy (1997) used a match-to-sample task in which 2-, 3- and 4-year olds were asked to choose between thematic (episodic) and taxonomic (semantic) alternatives. For example, after the experimenter picked up a carrot and labelled it, children were asked to choose between a rabbit (thematic choice) and a tomato (thematic choice). Waxman and Namy (1997) found no pervasive evidence for thematic over taxonomic choices even in the 2 year olds. Although their study did not investigate intra-word relations in young children's lexical memory (only the target object was labelled), their findings suggest that taxonomic relations have the potential to underpin the structure of lexical memory in young children.

Theoretical analyses of the structure of typical 30-month old vocabularies (Hills, Maouene, Maouene, Sheya, & Smith, 2009a, 2009b; Hills, Maouene, Riordan, & Smith, 2010) derived from CDI data (Fenson et al., 1994) and adult feature norms (McRae, Cree, Seidenberg, & McNorgan, 2005) show that these vocabularies possess the *small-world* and *scale-free* properties characteristic of adult semantic networks (Steyvers & Tenenbaum, 2005), and predict a *preferential acquisition* of new words on the basis of functional and perceptual feature overlap, frequency and phonological neighbourhoods in the learning environment. Hills et al. (2009b) argue that young children's lexical-conceptual networks have a clustering structure, based on perceptual and functional feature overlap, which resemble those found in adult taxonomic groupings. In a follow-up study, also analysing vocabulary development based on parental reports, Hills et al. (2010) argue for toddler's preferential acquisition of words based on adult associative norms. These theoretical analyses suggest that *both* semantic and associative relationships between words can mediate priming effects in the toddler lexical-semantic system. Evidence that such priming effects exist would provide support for the view that toddlers can exploit both associative and semantic relationships between lexical concepts when structuring their long-term semantic memories.

In adults and older children, the structure of the lexical-semantic system has primarily been investigated using lexical-decision or naming tasks. Pioneering work by Meyer and Schvaneveldt (1971) found that adults in a lexical decision task identified a target word (e.g., 'nurse') faster when related to a previously presented prime word (e.g., *doctor*) as compared with an unrelated word, suggesting that *doctor* and *nurse* are related in the adult lexicon. Subsequent studies with adults have found more reliable priming effects for words that are both semantically and associatively related (e.g., *dog–cat*) than for words that are only semantically (e.g., *dog–cow*) or associatively related (e.g., *dog–bone*), the so-called 'priming boost' (McRae & Boisvert, 1998; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; Perea & Rosa, 2002). These findings demonstrate that semantic and associative relatedness are factors that underpin the organisation of adult semantic memory.

In order to identify some of the structuring principles of semantic memory, considerable research effort has been expended to test whether priming effects for adults derive from purely associative effects or purely semantic effects (Alario, Segui, & Ferrand, 2000; Ferrand & New, 2003; Hodgson, 1991; McRae & Boisvert, 1998; Perea & Rosa, 2002; Thompson-Schill, Kurtz, & Gabrieli, 1998). Existing findings indicate that both types of effects are present: priming effects of semantic relations in the absence of normative association have been detected (Ferrand & New, 2003; Fischler, 1977; McRae & Boisvert, 1998; Thompson-Schill et al., 1998); priming for associated words in the absence of semantic relations have also been found (Ferrand & New, 2003; Hodgson, 1991; Williams, 1996). Different meta-analyses have also attested to the variability in these results. For example, Hutchison (2003) suggested that automatic priming is due to both associative strength and semantic feature

overlap. In contrast, a meta-analysis by Lucas (2000) argued that there is strong evidence for pure semantic priming but not for pure associative priming. However, both meta-analyses and other investigations (Alario et al., 2000; Lupker, 1985; McNamara, 2005) have stressed the fact that very often there is a confound between semantic and associative relatedness in the pairs used in the studies with adults. Furthermore, selection of word pairs, parameters of the task such as the stimulus onset asynchrony (SOA), inter-stimulus interval (ISI) and task demands have been shown to impact the observed pattern of priming effects (Anderson & Holcomb, 1995; Holcomb & Neville, 1990; Kotz & Holcomb, 1996; Moss et al., 1995; Williams, 1996). A recent neuroimaging study using fMRI with adults (Sachs, Weis, Krings, Huber, & Kircher, 2008) indicating that thematic/associative relations are processed similarly to taxonomic relations, but impose less demand on cerebral processing, provides further corroborating evidence for both types of conceptual relation in structuring adult lexical memory.

The research described in this paper is a first step to identify empirical evidence for the organisational principles underlying lexical development during infancy. Given the plethora of evidence for the impact of semantic and associative relationships in the structure of the adult lexical-semantic system, and the equivocal status of this evidence in pre-schoolers, we decided to investigate whether such relationships play any role in the formation of early lexical-semantic systems. A demonstration that associative and semantic relations between words have an impact on word recognition and understanding has the potential to offer important clues about *when* a lexical-semantic network emerges in young children and *how* such a system is organised.

That such a system underpins lexical-semantic memory in older children is now well-established. For example, Nation and Snowling (1999) found that both functionally (episodic/thematic) related words and category (taxonomic/semantic) related words primed 10-year-old normal and poor readers' reaction times in an auditory lexical decision task; category priming was obtained for normal readers even when prime-target word pairs had low associative strength. However, category priming was obtained with poor readers only if the prime-target word pairs shared high association strength, indicating that poor readers may be less sensitive to abstract semantic relations than normal readers. Schvaneveldt and colleagues (1977) showed that semantic context influences written word recognition in a lexical decision task: 7.6- and 9.5-year-olds, regardless of their reading skills, were faster and more accurate to read pairs of associated written words than non-associated words. McCauley and colleagues (1976) reported that whilst 8-year-olds showed facilitation for both thematically and taxonomically related pairs in a picture naming task, 6-year-olds' target naming was faster when a prime picture and a target picture were thematically related as opposed to taxonomically related. These investigations demonstrate older children's sensitivity to both thematic and taxonomic relationships between pairs of objects, pictures or words, though they tend to point to an early advantage for functional/episodic/thematic relationships over purely semantic/taxonomic ones.

Relatively few studies have explored the effect of semantic context on infants' lexical processing (Bowerman, 1978; Fernald, 2005; Friedrich & Friederici, 2004, 2005; Johnson, McQueen, & Huettig, 2011; Torkildsen, Syversen, Simonsen, Moen, & Lindgren, 2007). Torkildsen et al. (2007) presented auditory pairs of words drawn from the same or different superordinate category (e.g., 'dog'–'horse' versus 'car'–'apple') to 24-month-olds while event-related potentials (ERPs) were recorded. The results showed that words taken from the same superordinate category produced a smaller and delayed N400 effect compared to words from different superordinate categories, suggesting that words from the same superordinate category were taken as more closely related. The results reported by Torkildsen and her colleagues indicate the presence of priming effects for semantically related word pairs as early as 24 months of age, and point to the existence of a semantically-structured lexical memory in late infancy. However, it is not possible to conclude that the underlying semantic structures are organized according to taxonomic principles since the authors did not control for frequency of co-occurrence of the taxonomically related words.

Friedrich and Friederici (2004, 2005) report several EEG experiments which suggest the presence of priming-like effects in infants as early as 14 months of age: infant ERPs revealed an early negativity for congruous associations (the word 'dog' following a picture of a shoe), and a later N400-like negativity for incongruous associations (the word 'dog' following a picture of a cat). Although it is possible that these congruity effects might reflect intra-word relations in a lexical-semantic network, perhaps via implicit naming of the picture (cf. Mani & Plunkett, 2010), these results are also consistent with simple violation of expectation (NOT *dog*), unmediated by any internal structure in lexical memory. A recent study by Johnson et al. (2011) illustrates the plausibility of this latter interpretation: Johnson et al. (2011) used a target-absent, inter-modal preferential looking (IPL) design to investigate toddler's language-mediated visual search. For example, 24-month-olds were asked to find an absent target *monkey* when presented with a picture of a semantically related item (dog) and an unrelated distractor (apple). Toddler's preferred to look at the semantically-related item, indicating sensitivity to the conceptual relationship. Toddler's also showed a similar preference for a colour-related item, *even though they lacked a name for the colour*. For example, when asked to find an absent *tomato* when presented with a red mitten and a blue hat, they preferred to look at the red mitten. This finding demonstrates that language can influence the perceptual features used to guide visual search in young toddlers. It also demonstrates that such visual search need not rely on a semantically-structured lexical memory, and that care is required when attempting to infer the structural principles of lexical-semantic organization from studies in which only single target words are used (e.g., Fernald, 2005; Friedrich & Friederici, 2004, 2005; Waxman & Namy, 1997)

Two studies (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009a) have investigated lexical-semantic priming effects in late infancy for word pairs that are both semantically and associatively related – exploiting the

so-called 'priming boost', using an adaptation of the preferential looking task (Golinkoff, Hirsch-Pasek, Cauley, & Gordon, 1987). Styles and Plunkett (2009a) presented 18- and 24-month-old infants with pairs (prime-target) of related (*cat–dog*) or unrelated words (*plate–dog*) immediately prior to the presentation of a pair of pictures, target and distracter (dog–shoe), one of which depicted the target. Related word pairs were always semantically and associatively related ('cat'–'dog') whereas unrelated word pairs were neither semantically nor associatively related. Only the 24-month-olds demonstrated a priming effect, i.e., a difference between the related and unrelated conditions: they looked longer at the target picture when presented with related prime-target word pairs than when presented with unrelated prime-target word pairs. Styles and Plunkett (2009a) argued that these results were consistent with the view that by 24 months of age, infants have begun to develop a lexical network that is sensitive to conceptual relationships between the words in their lexicons. However, their study did not identify the locus of the priming effect. The absence of an appropriate baseline control condition meant that word–picture priming as well as word–word priming could equally well explain the pattern of results obtained with the 24-month olds.

A similar study by Arias-Trejo and Plunkett (2009) presented 18- and 21-month-old infants with prime-target word pairs that were associatively and semantically related (e.g., *cat–dog*) or pairs of unrelated words (e.g., *spoon–dog*) prior to the presentation of a picture pair (e.g., dog–door), one of which depicted the target. A modification of Styles and Plunkett's experimental design permitted an evaluation of whether infants respond to a meaning relation between the words rather than just to a relation between the prime word and the target picture. This was achieved by including related prime-only trials and comparing infants' performance on trials that presented prime-target word pairs (*cat–dog*) to prime-only trials in which the prime but not the target was named (*cat–look*). Arias-Trejo and Plunkett (2009) reported that the 21-month-olds demonstrated a priming effect: they looked longer at the target picture in the related condition compared to the unrelated condition, in which they demonstrated no systematic target preference. As in the Styles and Plunkett (2009a) study, 18-month-olds failed to demonstrate a priming effect. Furthermore, the older infants failed to demonstrate a target preference in the prime-only condition (e.g., *cat–look*, when the target picture dog was available but unnamed), indicating that the prime itself was insufficient to drive a target preference under the timing parameters used in the study.[1]

[1] Note that this condition is not unlike that used by Johnson et al. (2011) who *did* report looking preferences towards the related picture. However, the toddlers in Johnson et al.'s study had several seconds to examine the pictures before they heard the auditory label. In the Arias-Trejo and Plunkett (2009) study, auditory labels were presented before picture onset. These differences in timing confront the infant with somewhat different tasks in the two experiments. The structure of the Johnson et al. task encourages the infant to search for a match between a concurrently presented picture and an auditory label. In the Arias-Trejo & Plunkett task, the infant is required to remember the auditory label and then process the visual stimuli. Styles and Plunkett (2011) also report lack of target preference in toddlers in a similar prime-only design.

Thus, the priming effect appears to be mediated by the conceptual relations between the pairs of words rather than by a direct effect of the prime on the infants' preference for the target object.

Arias-Trejo and Plunkett's study indicates that 21-months-olds have begun to construct an inter-connected, lexical-semantic system in which words that are *both* semantically and associatively related are linked together. Insofar as failure to finding priming effects at 18 months of age suggests the absence of an interconnected lexical-semantic system, their results also suggest that there is a qualitative shift towards an adult-like organisation of the lexical-semantic system around the same time that many infants demonstrate dramatic increases in the size of their vocabularies.

The *manner* in which the 18-month-olds failed to demonstrate a priming effect is also indicative of the lexical-semantic processing responsible for priming at 21 months. Eighteen-month-olds were equally successful at identifying the target referent, irrespective of the priming condition, related or unrelated (a similar result was reported by Styles and Plunkett (2009a), with a different stimulus set). Just so long as the target was named they looked systematically longer at the target than at the distracter. In other words, across conditions, the 18-month-olds performed *better* than the 21-month-olds. This pattern of results suggests that an unrelated word *inhibits* identification of the named target referent for the older infants. Arias-Trejo and Plunkett (2009) contrast these results with the finding that both 18- and 21-month-olds readily identify the target referent if presented with only the target name immediately prior to presentation of the picture pairs. Consequently, the unrelated prime word in the unrelated condition must be interfering with target identification. Eighteen-month-olds are unaffected by unrelated prime words suggesting the absence of any inhibitory, competition effects.

Further support for the idea of the emergence of inhibitory, competitive processes in toddler's lexical processing comes from computational modelling work using TRACE (McClelland & Elman, 1986). Mayor & Plunkett (in preparation) simulated a wide range of published word recognition studies on lexical development by modifying TRACE's original lexicon to mimic vocabulary development from 18 to 24 months of age. In order to capture the pattern of results reported in studies with 18–19 month-olds (e.g., White & Morgan, 2008), it was necessary to "turn down" the lexical competition parameter so that words in the model were unable to inhibit each other. Keeping the lexical competition parameter "turned on" (the default adult setting in TRACE) lead to a pattern of results that was only observed in older toddlers. It should be noted that TRACE only implements phonological features and lexical representations. Hence, the inhibitory effects (or lack thereof) observed in the model are between phonological and lexical representations alone. Nevertheless, it is not implausible that the emergence of inhibitory processes at the level of phonological and lexical form might cascade to the processes involved in lexical-semantic structure.

The results of these priming studies with toddlers paint a picture of an emergent lexical-semantic system in which

words are organised in accordance with their joint semantic and associative properties. The findings are consistent with the recent theoretical analyses of young children's vocabulary development, based on parental report, indicating that words are incorporated into infant semantic networks on the basis of shared perceptual and functional features (Hills et al., 2009b; Steyvers & Tenenbaum, 2005). These theoretical analyses suggest that *both* semantic and associative relationships between words can separately mediate priming effects in the toddler lexical-semantic system. Evidence that such priming effects exist would provide support for the view that toddlers can exploit both associative and semantic relationships between lexical concepts when structuring their long-term semantic memories. The empirical findings (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009a) also suggest that the structure building processes hypothesised by Hills et al. (2009a, 2009b, 2010) should be supplemented with inhibitory mechanisms – a component not utilised within their theoretical framework.

Our goal in the current study is to explore the contribution of semantic and associative factors to early lexical-semantic network growth, following in the tradition of the investigation of these factors in the adult priming literature. We suppose that any early priming effects induced by semantic or associative relationships will provide important clues regarding the manner in which infants construct a network of meanings *en route* to mastering the adult lexical-semantic system. We focus on 21- and 24-month-old infants because previous studies have found priming effects at these ages (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009a). Following the logic that priming effects are strongest for word pairs that are semantically and associatively related, the so-called priming boost (Moss et al., 1995; Perea & Rosa, 2002), we predicted that 21-month-olds would show reduced priming effects for word pairs that are only taxonomically or associatively related, according to adult-defined norms. We included a group of 24-month-old infants in order to investigate the development of any such priming effects, and by inference the development of the lexical-semantic system.

The overall design of the study was very similar to Arias-Trejo and Plunkett (2009). We tested three priming conditions[2]: (1) related prime – target named, (2) related prime – target unnamed and (3) unrelated prime – target named. For simplicity, we will abbreviate these conditions as: (1) Prime-Target, (2) Prime-Look and (3) Neutral-Target. Comparison of conditions 1 and 3 permits the identification of a priming effect: a related word should prime a target name whereas an unrelated word should not. Comparison of conditions 1 and 2 permits an evaluation of the impact of the related prime in the absence of a target name. In contrast to Arias-Trejo and Plunkett (2009), related word pairs are *either* semantically *or* associatively related, not both. This experimental design permits an evaluation of the impact of semantic and associative relationships on the underlying structure of lexical-semantic networks in early childhood.

2. Method

2.1. Participants

Fifty 21-month-olds (27 males, 23 females) and fifty-four 24-month-olds (26 males, 28 females) participated. The mean ages were: 21:00 months (range 20:15–21:15) and 24:05 months (range 23:17–24:20). Half of the infants in each age group were allocated to each word-relationship condition, Associative or Taxonomic. The data from four 21-month-olds was not analysed due to their lack of familiarity with 50% or more of the presented words as reported by their parents ($n = 1$), their failure to pay attention to more than 50% of the trials ($n = 1$) and experimental error ($n = 2$). All infants had no known hearing or visual problems and were recruited from local maternity wards and playgroups. Infants came from homes where British English was the primary language.

2.2. Stimuli

In order to distinguish precisely between the two types of conceptual relations, we defined associative word pairs as free-associative norms with no categorical relatedness. We do not imply that our associative pairs do not share semantic relations where 'semantic' is defined in a broader sense.[3] Associative relationships are often assumed to derive from linguistic or thematic co-occurrence, such as in utterances or physical events (Thompson-Schill et al., 1998). We define two words as purely taxonomically related[4] if they refer to objects belonging to different basic-level categories which are hierarchically related, often by a common superordinate term (e.g., *animal* for dog–rabbit), and that these words are not associatively related, according to adult norms. Taxonomic relationships are often thought to derive from overlap in semantic features, perceptual, conceptual or functional (Thompson-Schill et al., 1998). With this contrast in mind, we selected word pairs that were associated according to adults' norms (Kiss, Armstrong, Milroy, & Piper, 1973; Moss & Older, 1996) but that were not taxonomically related (e.g., rabbit–carrot) and pairs of taxonomically related words restricted to categorical coordinates with null associative strength according to such norms (e.g., cow–bird). Note that the use of adult associative norms provides only a first approximation to the likelihood of infants and young children possessing similar associations. However, the absence of an associative relationship in adulthood is likely to be a strong indicator of its absence in infancy and early childhood. Taxonomically related words in early development need not necessarily conform to adult norms either. Toddlers may over- or under-extend their taxonomic cate-

[2] We eliminated the fourth condition (Neutral-Look) used in Arias-Trejo & Plunkett (2009) since it provides no useful additional information regarding priming effects or object salience. Note that all pictures used in the current study served as both target and distracters across infants.

[3] McNamara (2005) has emphasized the difficulty of finding associatively related word pairs in the absence of semantic relatedness where semantic relatedness is defined in a broader sense as relations in meaning.

[4] We prefer the term "taxonomically related" to "semantically related" to avoid any confusion associated with the term "semantic" and not to prejudge whether the relationship is encoded in the language system.

gories, such that the absence of a taxonomic relationship in the adult may, in fact, exist for the child, or indeed *vice versa*. That our participants are familiar with the lexical contrasts used in the experiment, as assessed by parental report, offers some indication that they are also familiar with similar taxonomic contrasts (see Styles & Plunkett, 2009b for experimental evidence for this claim). Nevertheless, the choice of taxonomic word pairs must also be considered a first approximation for any given infant. We will return to these sources of approximation in our interpretation of the experimental results.

Sixty-two concrete nouns were selected from two data sources: the Oxford Communicative Developmental Inventory (Hamilton, Plunkett, & Schafer, 2000) and the Lexical Development Norms Database, LEX (Dale & Fenson, 1993). The criterion of selection was that words had to be above the 60th percentile for infants' receptive vocabulary from the age of 18 months, as reported by the frequency of familiarity in the databases. Thirty-six words were used in each condition, of which 10 words overlap. From these words, 18 served exclusively as primes and 18 exclusively as targets. Targets were paired with distracters such that their labels shared the same phonological onset and were selected so that there was neither attested associative strength nor a semantic relationship between them. Shared phonological onsets prevented the infant from using the initial sound in the target word to identify the correct picture (Fernald, Swingley, & Pinto, 2001). With the aim of avoiding phonological priming effects (Mani & Plunkett, 2010, 2011), the prime label had a different phonological onset to the target and distracter labels in all cases.

In the Associative condition, a prime word (e.g., *nappy*) was associatively related to the label of one member of a target-distracter pair (e.g., baby-bunny) whilst another prime word (e.g., *carrot*) was associatively related to the other member of the pair. The prime-target pairs were selected to be associated according to published adult associative norms (Kiss et al., 1973; Moss & Older, 1996). Note that the strength of the association varies considerably (from 39 to 1.1) due to the restricted number of word pairs that could be formed with the words familiar to 21-month-olds. Pairs with high associative strength tend to be selected for adult studies exploring semantic-associative effects. However, studies attempting to dissociate between semantic and associative priming often use pairs of low to moderate associative strength to avoid semantic overlap (see Lucas, 2000 for a review).

In the Taxonomic condition, a prime word (e.g., *table*) was taxonomically related to the label of one member of a target-distracter pair (e.g., bed-bike) whilst another prime word (e.g., lorry) was taxonomically related to the other member of the pair. The prime-target pairs in the taxonomic condition were selected to have null associative strength according to adult associative norms (Kiss et al., 1973; Moss & Older, 1996). Although some studies have reported children's word association norms (Entwisle, 1966; Koff, 1965; Palermo & Jenkins, 1999), they have proved to be unsuitable for use with our infants for the following reasons: (1) the majority of the sample words are not part of infants' vocabularies (e.g., cabbage), (2) the sample nouns are not necessarily readily imageable (e.g., light) and (3) they include word categories other than nouns (e.g., verbs and adjectives) which are not the target of study of this work. The British norms employed for the purpose of this research (Kiss et al., 1973; Moss & Older, 1996) included a sufficient number of nouns that could be presented to infants under the age of two. Furthermore, the input to British infants may well reflect the associative norms found for British adults and contribute to the underlying associations that infants form themselves, as suggested by the results reported in recent studies (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009a). The taxonomically related words were chosen according to the constraint that the prime and target items were drawn from the same superordinate category without being associatively related and that infants were familiar with the prime-target-distracter words according to the vocabulary norms mentioned above.

For both word-relationship conditions, the target, distracter and prime words were all highly imageable (Bird, Franklin, & Howard, 2001; Cortese & Fugett, 2004). Tables 1 and 2 list all possible target-distracter pairings used in both word-relationship conditions. Note that neither labels nor pictures were repeated for individual infants. For both word-relationship conditions, each object in a trial served as a target and a distracter across infants.

All auditory stimuli were digitally recorded in the same session by a female voice in child-directed speech at

Table 1
Target and distracter pairings used for the 18 triads in the associative condition in Prime-Target and Neutral-Target trials.

Related prime	Target	Distracter	Assoc. strength	Unrelated prime	Related prime	Target	Distracter	Assoc. strength	Unrelated prime
Nappy	Baby	Bunny	NA/39	Knife	Cup	Milk	Monkey	4.1	Toys
Hand	Glove	Glass	21.4	Egg	Cereal	Bowl	Bird	2.4	Foot
Toys	Child	Chicken	16.7	Banana	Plate	Cake	Key	2.2	Nappy
Carrot	Bunny	Baby	10	Plate	Park	Swing	Sock	2.1	Water
Egg	Chicken	Child	7.1	Door	Door	Key	Cake	2.1	Park
Pictures	Book	Bottle	NA/7	Carrot	Water	Bottle	Book	2	Sky
Foot	Sock	Swing	4.3	Cereal	Banana	Monkey	Milk	1.1	Pictures
Soap	Bath	Bread	4.2	Hand	Sky	Bird	Bowl	NA/1	Juice
Knife	Bread	Bath	4.2	Cup	Juice	Glass	Glove	NA/1	Soap

Note. The first figure in the associative strength column denotes the percentage rates of adults who produced the target word in Moss and Older (1996). The second figure next to the abbreviation NA corresponds to Kiss et al. (1973) for the cases in which the input word was not available in Moss and Older (1996).

Table 2
Target and distracter pairings used for the 18 triads in the taxonomic condition in Prime-Target and Neutral-Target trials.

Related prime	Unrelated prime	Target	Distracter	Related prime	Unrelated prime	Target	Distracter
Plate	Lorry	Bottle	Bird	Cow	Coat	Bird	Bottle
Biscuit	Dog	Carrot	Cot	Chair	Lion	Cot	Carrot
Coat	Cat	Sock	Spoon	Glass	Rabbit	Spoon	Sock
Dog	Bib	Chicken	Cheese	Orange	Plane	Cheese	Chicken
Table	Apple	Bed	Bike	Lorry	Table	Bike	Bed
Lion	Chair	Monkey	Milk	Water	Nappy	Milk	Monkey
Rabbit	Biscuit	Horse	Hat	Bib	Plate	Hat	Horse
Aeroplane	Cow	Car	Cake	Apple	Glass	Cake	Car
Nappy	Orange	Shoe	Sheep	Cat	Water	Sheep	Shoe

Note. These pairs had null associative strength according to the adult norms employed.

22.05 kHz into signed, 16-bit files. They were edited to remove background noise, head and tail clicks and to match for peak-to-peak amplitude. The eighteen target words were recorded in isolation. The prime words were embedded in one of the following carrier phrases: '*I saw a*/*I bought a*/*I got a*'. The prime word was always placed at the end of the sentence. The word '*Look*' was also recorded for use in Prime-Look trials.

Visual stimuli: Eighteen images of the selected target-distracter pairs were employed in each experiment. Images were colourful computerised photos of typical exemplars of real objects. All images were the same size (320 × 320 pixels) and had five percent grey background to reduce brightness on the screen.

2.3. Procedure

We used an adaptation of the Inter-modal Preferential Looking task (Golinkoff et al., 1987) previously used to test early priming effects (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009a). The infant sat centrally on his/her caregiver's lap in front of a large screen that displayed the visual stimuli. The target-distracter images were shown at the infant's eye-level, at a distance of approximately 70 cm. Each image measured 32 × 32 cm and were displayed 30 cm apart. Two loudspeakers presenting the auditory message were mounted centrally above the screen. Two hidden miniature video cameras mounted side by side above the screen and aligned to the horizontal midpoint of each picture permitted digital recording of a split screen twin-image of the infant's visual fixation on each image. Parents were instructed to remain quiet, close their eyes and wear headphones through which they heard music, in order to avoid influencing the infant's eye fixations during the presentation of the stimuli. The experimenter remained out of the infant's sight during the task and managed the experimental computer. The pocedure lasted for about two minutes.

2.4. Experimental design

We used a short prime-target inter-stimulus interval (ISI) and a short stimulus-onset asynchrony (SOA) of 200 ms each (see Fig. 1). ISI is the time between the offset of the prime word and the onset of the target word. SOA is the time elapsed between the onset of the target word and the onset of the visual stimuli. These parameters were also used with infants by Arias-Trejo and Plunkett (2009) and Styles and Plunkett (2009a, 2011). They correspond to timing parameters that are associated with automatic lexical priming effects in the adult literature.

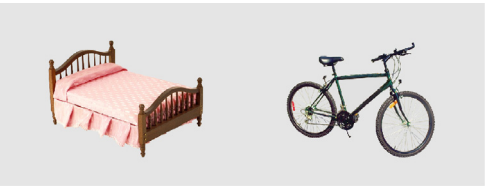
The procedure consisted of nine trials, three per priming condition: (1) Prime-Target (e.g., *lorry–bike*), (2) Prime-Look (e.g., *lorry–look*) and (3) Neutral-Target (e.g., *apple–bike*). In Prime-Target trials, the prime word is either associatively (Associative condition) or taxonomically (Taxonomic condition) related to the named target image. In Prime-Look trials, although there is an associative or taxonomic relationship between the prime and the target, the target image is unnamed. Prime-Look trials permit an evaluation of the impact of the prime label in the absence of the target name. In Neutral-Target trials, the prime is unrelated to the named target and the distracter. Any priming effect can be measured by comparing the related and unrelated priming conditions.[5] Table 3 lists an example set of the nine pairs in each word-relationship condition.

Each trial consisted of the following sequence: first, the carrier phrase, which ended with the prime word, was delivered over the loudspeakers; 200–500 ms after the beginning of the carrier phrase, an attention getter (a static circle with smooth, pale and uniform contours of red, blue and yellow) appeared at the centre of the screen for 1000 ms and then disappeared 200 ms before the onset of the prime word. 200 ms after the offset of the prime word, the target word was delivered. Finally, 200 ms after the onset of the target word, the two pictures (target and distracter) appeared simultaneously and remained visible for 2500 ms.

After completion of a trial, the next trial sequence started as soon as the infant fixated the screen, as monitored by the experimenter. Each infant saw the nine pairs of target-distracter pictures just once. Six different presentations of the nine image pairings were created. Thus, each picture served as a target the same number of times within

[5] Recall that both images in the picture pairs serve equally often as target and distracter across infants, thereby counterbalancing any effects owing to systematic differences in picture salience. Note also that Arias-Trejo and Plunkett (2009) report an experiment involving a Target only presentation which produced robust target preferences even when target and distracter have labels beginning with the same onset consonant. Other unpublished studies in our laboratory have demonstrated robust target preferences in a Target alone condition across a broad range of SOAs (200–2000 ms).

Prime-Target: I saw a **lorry … bike**
Prime-Look: I saw a **lorry … look**
Neutral-Target: I saw an **apple … bike**



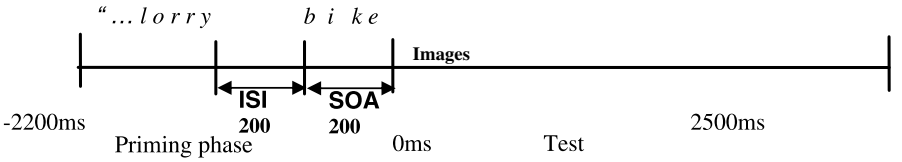


Fig. 1. Example of a trial sequence used in Experiment 1.

Table 3
Example of trials presented in a set for each word-relationship type.

	Taxonomic trials			Associative trials			
	Prime	Target	Distracter	Prime	Target	Distracter	Trial Type
1	Plate	Bottle	Bird	Water	Bottle	Book	Prime-target
2	Chair	Cot	Carrot	Park	Swing	Sock	Prime-target
3	Coat	Sock	Spoon	Juice	Glass	Glove	Prime-target
4	Dog	Chicken	Cheese	Plate	Cake	Key	Prime-look
5	Table	Bed	Bike	Soap	Bath	Bread	Prime-look
6	Water	Milk	Monkey	Carrot	Bunny	Baby	Prime-look
7	Biscuit	Horse	Hat	Foot	Bowl	Bird	Neutral-target
8	Glass	Cake	Car	Pictures	Monkey	Milk	Neutral-target
9	Orange	Shoe	Sheep	Door	Chicken	Child	Neutral-target

Note. Trials were presented in a random order with the constraint that no more than two trial types were presented consecutively.

each priming condition across infants (e.g., the image of a bottle was the target the same number of times in Prime-Target, Prime-Look and Neutral-Target trials). No infant saw more than two consecutive trials from the same condition. The side of presentation of a particular picture (left–right) and the corresponding target and distracter side were counterbalanced across and within infants, respectively. Fig. 1 displays an example of a trial sequence, along with the three priming conditions.

3. Results

The experimenter, blind to which particular images and auditory stimuli were being presented, assessed the digital videos off-line frame-by-frame (every 40 ms) to determine the direction and duration of each fixation (left, right or other). A second skilled coder evaluated the data from 10% of the participants. Agreement between scorers, assessed by computing Pearson's correlation coefficients was $r = .97$, $p < .001$. Intra-scorer mean reliability was $r = .98$, $p < .001$.

For each infant, individual trials that contained unfamiliar names, as reported by parents using a British adaptation of the MacArthur Communicative Development Inventory (Hamilton et al., 2000) were excluded from the analysis. This assessment aimed to ensure that each infant was evaluated only on their understanding of familiar words. After exclusion of missing trials or trials presenting an unknown word, there were 185 trials (98%) from the 189 original trials presented in the Associative condition and 219 trials (97%) from the 225 original trials presented in the Taxonomic condition to the 21-month-olds. For the 24-month-olds, there were 232 trials (95%) from the 243 originally presented in the Associative condition and 237 (97%) from the 243 trials originally presented in the Taxonomic condition. At both ages, there were no significant differences between the distributions of the trials per condition. Each infant's looking-times were aggregated by condition creating a participant mean for each of the three conditions.

At picture onset in the taxonomic condition, 21-month-old infants were fixated centrally on 210 (96%) out of a total of 219 trials. Similarly, 24-month-olds were centrally fixated at picture onset in 224 (95%) out of a total of 237 trials. In the associative condition, there were 181 centrally-fixated trials (97%) out of a total of 185, and 217 (94%) out of a total of 232, for the 21- and 24-month-olds

Table 4
Mean proportion of target looking and longest look difference by age, priming condition and word-relationship.

	Prime-Target			Prime-Look			Neutral-Target		
	Associative	Taxonomic	Combined	Associative	Taxonomic	Combined	Associative	Taxonomic	Combined
PTL	Proportion of target looking								
21 m									
M	0.58	0.57	0.58	0.51	0.48	0.49	0.56	0.60	0.58
SD	0.10	0.17	0.14	0.17	0.17	0.17	0.10	0.12	0.11
24 m									
M	0.59	0.55	0.57	0.52	0.49	0.51	0.50	0.52	0.51
SD	0.15	0.14	0.14	0.14	0.12	0.13	0.13	0.14	0.13
LLK	Longest look difference								
21 m									
M	312	268	288	61	−73	−12	273	361	321
SD	405	659	553	66	633	643	349	471	417
24 m									
M	400	247	323	170	−37	66	50	78	64
SD	600	591	595	560	460	517	514	606	557

respectively. In the taxonomic condition, first looks were quite evenly distributed between the target and the distracter images at 21-month-olds (target looks = 93, distracter looks = 117; χ^2 (1, $N = 210$) = 2.74, $p = .10$) and 24 months of age (target looks = 122, distracter looks = 102; χ^2 (1, $N = 224$) = 1.79, $p = .18$). Similarly, in the associative condition, first looks were evenly distributed between the target and the distracter images at 21-month-olds (target looks = 91, distracter looks = 90; χ^2 (1, $N = 181$) = .006, $p = .94$) and 24-months-old (target looks = 105, distracter looks = 112; χ^2 (1, $N = 217$) = .23, $p = .63$). Further tests indicated that at both ages, infants' first looks failed to demonstrate any systematic preference for the target or for the distracter in any of the three priming conditions (all $ps > .23$).

The proportion of total looking (PTL) and longest looks (LLK) were calculated for the 2500 ms of picture presentation. PTL is the proportion of target looking out of the total looking time to the target (T) and to the distracter (D): (T/$T + D$). LLK difference compares looking at the target relative to the distracter by calculating the difference (t–d) between the single longest look to the target (t) and to the distracter (d). Similar results were obtained with both measures.

Preliminary analyses revealed no effects or interactions with participants' sex; therefore, those variables were omitted from further analysis. We also failed to find a significant contribution of vocabulary scores on children's performance. Table 4 shows that 21- and 24-month-olds prefer to look at the target over the distracter in Prime-Target trials whereas target looking is around chance level for both age groups in Prime-Look trials, irrespective of the Associative or Taxonomic nature of the prime word. However, a difference in target looking between the age groups is apparent for Neutral-Target trials: 21-month-olds show a systematic target preference whereas 24-month-olds exhibit unsystematic looking, again irrespective of Associative or Taxonomic condition. Comparisons to chance (0.5) with PTL indicated that 21-month-olds looked significantly above chance in Prime-Target trials ($t(45) = 3.64$, $p = .001$) and in Neutral-Target trials ($t(45) = 5.04$, $p = .0001$) but not in Prime-Look trials ($t(45) = .34$, $p = .74$). For the 24-month-olds, target looking above chance level was shown exclusively in Prime-Target trials ($t(53) = 3.39$, $p = .001$); other trial types: Prime-Look ($t(53) = .40$, $p = .69$) and Neutral-Target ($t(53) = .43$, $p = .67$). An identical pattern of results was observed with the LLK measure. Twenty-one-month-olds looked significantly above chance in Prime-Target ($t(45) = 3.53$, $p = .001$) and Neutral-Target trials ($t(45) = 5.21$, $p = .001$) but not in Prime-Look trials ($t(45) = .13$, $p = .90$). For the 24-month-olds, target looking above chance level was shown exclusively in Prime-Target trials ($t(53) = 3.99$, $p = .001$); other trial types: Prime-Look ($t(53) = .94$, $p = .35$) and Neutral-Target ($t(53) = .85$, $p = .40$).[6]

A 3 × 2 × 2 mixed model analysis of variance (ANOVA) with the factor Priming condition (PT–PL–NT) as a within-subjects factor, and Word-Relationship (Associative and Taxonomic) and Age (21-month-olds and 24-month-olds) as between-subjects factors was performed. With the LLK measure, the analysis revealed a main effect of Priming condition ($F(2,95) = 5.92$, $p = .004$, $\eta^2 = .111$) and a marginally significant interaction between Age × Priming condition ($F(2,95) = 2.56$, $p = .08$, $\eta^2 = .051$). With the PTL measure, the analysis also revealed a main effect of Priming condition ($F(2,95) = 6.65$, $p = .002$, $\eta^2 = .123$) and a marginally significant interaction between Age × Priming condition ($F(2,95) = 2.38$, $p = .098$, $\eta^2 = .048$). There was

[6] Item analyses were conducted to determine whether individual pairs, from the nine presented in each word-relationship condition produced similar responses to the overall pattern of results. Because each word-relationship condition presented nine different pairs, we performed an analysis of variance with LLK as a dependent variable, and the factors Pairs (1–9), Priming condition (Prime-Target, Prime-Look and Neutral-Target) and Age (21- and 24-month-olds), separately for each word-relationship condition. The analysis did not produce an effect of Pairs nor a significant interaction between Pairs and another factor (all $ps > .10$). These results indicate that infants performed in a similar manner with all nine pairs in both word-relationship conditions.

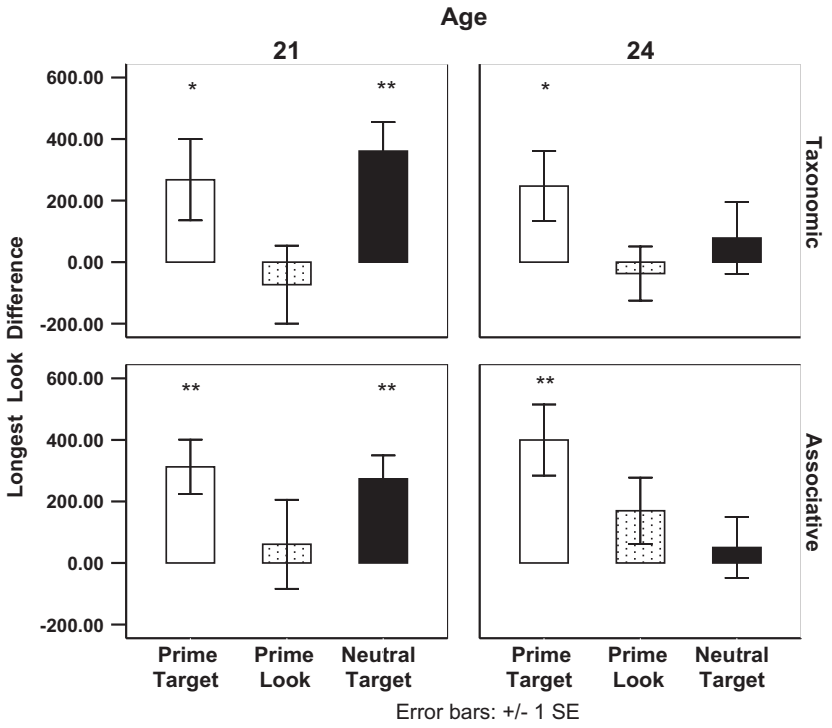


Fig. 2. Mean (±1SE) target minus distracter preference with the LLK measure for both ages according to the priming condition, split by associative and taxonomic trials. Above chance target looking $^{*}p < .05$ and $^{**}p < .01$.

no main effect or interactions involving the factor Word-Relationship.

The marginal two-way interaction suggested that the effect of prime condition was different between the two age groups. Therefore, we compared infants' target looking between the priming conditions, separately for each age group but combining both word-relationship conditions, associative and taxonomic, since the ANOVA offered no hint of a difference between them. To evaluate the overall priming effect, we contrasted infants' target preferences in Prime-Target trials versus Neutral-Target trials. With the LLK measure, target preferences in Prime-Target trials differed from target preferences in Neutral-Target trials for the 24-month-olds ($t(53) = 2.39$, $p = .020$, $d = .45$) but not for the 21-month-olds ($t(45) = .32$, $p = .75$). We also contrasted Prime-Target trials with Prime-Look trials to evaluate the impact of naming the target: at both ages, the preference for the target image differed significantly between the two types of trials ($t(45) = 2.53$, $p = .015$, $d = .50$) and ($t(53) = 2.43$, $p = .018$, $d = .46$) for the 21- and 24-month-olds, respectively. Finally, target preference in Neutral-Target trials was significantly longer than in Prime-Look trials at 21 months ($t(45) = 2.77$, $p = .008$, $d = .61$) but did not differ at 24 months of age ($t(53) = .017$, $p = .99$). Fig. 2 displays target preference with the LLK measure for both ages according to the three prime-target conditions (split by associative and taxonomic conditions). The PTL measure revealed the same pattern of results: target preferences in Prime-Target trials differed from target preferences in Neutral-Target trials for the 24-month-olds ($t(53) = 2.20$, $p = .032$, $d = .43$) but not for the 21-month-olds ($t(45) = .20$, $p = .84$). At both ages, the preference for the target image differed significantly between Prime-Target trials and Prime-Look trials: ($t(45) = 2.84$, $p = .007$, $d = .54$) and ($t(53) = 2.38$, $p = .021$, $d = .42$) for the 21- and 24-month-olds, respectively. Finally, target preferences in Neutral-Target trials were significantly longer than in Prime-Look trials at 21 months ($t(45) = 2.78$, $p = .008$, $d = .63$) but did not differ at 24 months ($t(53) = .030$, $p = .98$).

In summary, the target preferences of the 21- and 24-month olds differed, as measured with PTL and LLK, depending on whether the prime and the target words were related or unrelated to each other. At 21 months, infants showed a target preference when the target object was named, irrespective of whether the target was primed by a related (Prime-Target) or unrelated word (Neutral-Target), but failed to show any systematic preference if the target was unnamed (Prime-Look) either when preceded by an associatively or taxonomically related prime. In contrast, 24-month-olds showed systematic target preference only in Prime-Target trials. This was the case for both word-relationship conditions, associative and taxonomic.

4. Discussion

This study investigated whether 21- and 24-month-olds possess an understanding of the lexical-semantic relationships between words that are either associatively or taxonomically related, according to adult norms. We evaluated

infants' visual target preferences when exposed to three different trial types. In Prime-Target trials infants were exposed to two associatively or taxonomically related words, the second of which named a target picture. In Prime-Look trials, infants heard a prime word that was related, associatively or taxonomically, to an unnamed target picture. In Neutral-Target trials, infants were exposed to two unrelated words, in which the second word named a target picture.

The results indicated two main findings: (1) 24-month-olds, but not 21-month-olds showed a priming effect, as evidenced by the difference in target preferences between the Prime-Target and the Neutral-Target conditions and (2) priming effects were observed for both types of lexical-semantic relationships, associative and taxonomic.

In accordance with our prediction, 21-month-olds revealed no evidence for the formation of lexical-semantic links between words which are *only* associatively or taxonomically related according to adult norms. At this age, infants exhibit systematic target looking irrespective of whether the previous prime word is related (Prime-Target) or unrelated (Neutral-Target) to the target word. In contrast, 24-month-olds show a priming effect for both types of meaning relationships: they look longer at the target compared to the distracter in Prime-Target trials compared to Neutral-Target trials. Thus, 24-month-olds seem to be sensitive to the relationship between two words that are drawn from the same taxonomy (e.g., lorry–bike) even in the absence of any associative relationship, or words that are associated according to adult norms (e.g., park-swing), even in the absence of any taxonomic relationship. This suggests that 24-month-old infants can integrate words into an inter-connected lexical-semantic system on the basis of *either* associative or taxonomic relatedness, whereas 21-month-olds cannot.

When considering the *overall* performance (amount of target looking) across the three priming conditions, it is apparent that 21-month-olds perform *better* than the 24-month-olds (see Fig. 2). The difference is carried by the Neutral-Target condition: 21-month-olds show target recognition in this condition whereas 24-month-olds do not. Twenty-one-month-olds prefer to look at the target picture just so long as it is named. We attribute this *deterioration* in performance of the 24-month-olds to the emergence of a lexical-semantic network which highlights the semantic similarity between words: related words prime each other whereas unrelated words interfere with each other. In an unstructured lexicon where there is no representation of semantic similarity, the distinction between related and unrelated words is mute and words are equally well-recognised in either priming condition. This developmental trajectory from good to poorer performance is well-precedented in the developmental literature (e.g., Berko, 1958; Karmiloff-Smith, 1986, 1992), and is often interpreted as manifesting a process of structural reorganisation. For example, Karmiloff-Smith (1992) catalogues a range of cognitive abilities which deteriorate temporarily following a period of apparent mastery. She attributes this decrement in performance to a process of *representational redescription* in which cognitive representations are reorganised to a more abstract form. The process of reorganisation acts as a double-edged sword resulting in poorer performance in the older children. In the current context, the 24-month-olds' deterioration in performance can be seen as a consequence of a reorganisation, or representational redescription, of lexical memory into a network of related meanings.

Twenty-one and 24-month olds exhibit similar patterns of performance in Prime-Look trials: neither age group demonstrated a systematic preference for the unnamed target image when exposed to an associatively or taxonomically related prime. This result indicates that hearing a related prime word is insufficient to trigger identification of an unnamed target referent in this task, where the offset of the prime occurs 400 ms prior to picture onset. It also indicates that 24-month-olds' target looking in Prime-Target trials is the product of hearing the related word pairs rather than just the result of an association between the related prime word and a picture. This finding replicates infants' behaviour in similar Prime-Look trials reported by Arias-Trejo and Plunkett (2009), where the prime word was both associatively and taxonomically related to the target image. Styles and Plunkett (2011) also report lack of a target preference in a Prime only condition using timing parameters almost identical to those in the current study. Note that under some circumstances words can elicit infant fixations to perceptually related targets even when the word mismatches the target. Thus, Johnson et al. (2011) found that 24-month-olds would preferentially fixate a picture of a red plane upon hearing the word "strawberry". However, the participants in Johnson et al.'s study were allowed to view the visual objects for 4 s before hearing the word. In the current study and others using similar timing parameters, the objects are not available for viewing before hearing the target word and hence the locus of the active representations (phonological, semantic, perceptual) involved in word-picture matching may be quite different. It should also be noted that the verb included in the carrier phrases in which the prime word was embedded did not provide supporting context that could have favoured some representations of expected target words, as has been found in previous studies showing young children and adults' anticipatory eye fixations on objects that are appropriate arguments of a verb (Altmann & Kamide, 1999; Fernald, 2005).

Although the pattern of results reported in the current study enable us to assert the presence of taxonomic and associative priming effects in the 24-month-old lexical-semantic system, the direction of the reported priming effect does not permit unambiguous identification of the nature of the priming mechanism involved. For example, the unrelated prime may interfere with target word processing, or the related prime may facilitate processing, or both. However, findings from a previous infant priming study using similar timing parameters and stimuli provides strong clues as to the nature of the priming effect observed in the current study. Arias-Trejo and Plunkett (2009) compared a Target alone condition with a Neutral-Target condition. Their Neutral-Target condition failed to elicit systematic target preferences, replicating the current results, while the Target alone condition elicited robust target preferences. Arias-Trejo and Plunkett (2009)

concluded that the unrelated prime produced an interfering effect on target recognition. Given that the stimuli for both studies were drawn from a highly overlapping set, the behaviour of the older infants in the current study is consistent with the interpretation that unrelated primes interfere with target recognition whereas related primes do not.

In contrast to the current study, Arias-Trejo and Plunkett (2009) report priming effects in 21-month-olds. These precocious priming effects are readily attributed to the priming boost associated with the word pairs used in their study that are both taxonomically and associatively related. In adults, associatively and taxonomically related words always produce stronger priming effects than words related only at one level (McRae & Boisvert, 1998; Moss et al., 1995; Perea & Rosa, 2002). The absence of priming effects for 21-month-olds' in the current study can be explained by the absence of a priming boost since related word pairs were *only* taxonomically *or* associatively related. That the experimental manipulation of removing the priming boost also removed the priming effect, attests to the young participants' sensitivity to both taxonomic and associative relationships. If the 21-month-olds had been primarily sensitive to just one type of relationship, then we would have expected priming effects to remain intact in the corresponding experimental condition. No such effects were found. Note also that it is implausible that the differences between Arias-Trejo and Plunkett (2009) and the current study can be attributed to other factors such as processing speed, word familiarity or frequency effects since age, timing parameters and stimulus materials were almost identical. The essential difference between the current study and Arias-Trejo and Plunkett (2009) is the nature of the *relationship* between the lexical items.

We have argued that the priming effects observed in this study derive from inhibitory sources: unrelated primes interfere with target recognition whereas related primes do not. This result hold for both associatively and taxonomically related words. Similar inhibitory effects have been reported by Arias-Trejo and Plunkett (2009), and by Styles and Plunkett (2009a) with a different set of stimulus materials for word pairs that are both taxonomically and associatively related. Adult lexical priming studies report both excitatory and inhibitory effects (McNamara, 2005). Although we cannot rule out a role for facilitation in these infant studies, the prevalence of interference effects in this study makes sense in terms of infants' developing vocabulary and points to some initial organisational principles in early lexical-semantic networks. Vocabulary growth takes a dramatic leap forward for many infants during the second half of the second year of life. For the first time in her life, the infant's efficient comprehension of speech calls for rapid elimination of a potentially substantial number of meaningful competitors. For example, Mani and Plunkett (2011) have documented the emergence of cohort effects during this period of vocabulary development. An efficient and well-understood mechanism for the elimination of competing candidates is inhibition (see Mayor & Plunkett, in preparation, for a computational implementation of inhibitory processes in the infant lexicon). It is therefore plausible that inhibitory mechanisms play a key role in the structural processes guiding the construction of early lexical-semantic systems. Such inhibitory mechanisms can operate hand-in-hand with the structure building processes in toddlers' semantic networks, based on taxonomic and associative relationships, proposed by Hills et al. (2010, 2009a).

This study has identified associative and taxonomic relationships between words as being implicated in the young child's construction of a lexical-semantic system. The stimuli selection procedure was motivated by adult norms. As noted in the Introduction, it is unlikely that our young participants conform precisely to these norms. Nevertheless, we have adopted the assumption that adult norms form a first approximation to that of the young child. This assumption was supported by findings from theoretical analyses of early vocabulary growth demonstrating that both adult taxonomic and associative norms are predictive of preferential acquisition of new words by young children (Hills et al., 2009b, 2010), as assessed by parental questionnaires. Our experimental findings reinforce the assumption that young children are sensitive to similar associative and taxonomic contingencies reported in semantic priming studies with adults: Twenty-four month olds show priming effects only for word pairs that are taxonomically or associatively related according to adult norms. Of course, this finding does not imply that our young participants have the same taxonomic and associative organisation as adults, only that there is a concordance between their organisational structures. Adult-priming effects are significantly influenced by word frequency and familiarity, length of prime words, imageability, timing parameters (SOAs and ISIs) and possible strategic factors, as well as types of relationships (Hutchison, Balota, Cortese, & Watson, 2008). The discovery that systematic manipulation of associative and taxonomic factors also impacts priming effects with toddlers holds the promise that investigation of these other factors will further enlighten our understanding of the structures and processes underlying the young child's construction of a lexical-semantic system.

5. Conclusions

Earlier empirical investigations of the structure of lexical memory in young children challenged the prevailing view that early word meanings are initially represented independently of each other (Anglin, 1970; McNeill, 1970). Analyses of errors in speech production (Bowerman, 1978), word-associations (Petrey, 1977), false recognition tasks (Mansfield, 1977) and free- and cued-recall tasks (Blewitt & Toppino, 1991; Lucariello & Nelson, 1985), all indicate that a structured lexical-semantic system based on functional, perceptual, episodic and associative relationships is in place by early childhood. Theoretical analyses of the structure of typical 30-month old vocabularies (Hills et al., 2009a, 2009b, 2010) point to the existence of a structured lexical memory in which words are organised according to similarity of meaning, based on functional and perceptual feature overlap. This convergent pattern of experimental and theoretical findings conveys a picture of

continuity in the development of childhood lexical memory in which structural similarities to the adult lexical-semantic system are apparent from as early as 30-months of age.

The findings of the current study and other recent findings (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009a, 2011; Torkildsen et al., 2007) corroborate, extend and attenuate this picture of continuity in several important ways. First, our results indicate that associative and taxonomic relationships between words are implicated in the structuring of infant lexical memory as early as 21–24 months of age. This finding highlights the *continuity of structure* in the development of children's lexical memory and offers further experimental support for the use of adult-based feature norms underlying previous theoretical analyses of young children's vocabularies (Hills et al., 2009a, 2009b, 2010). However, we suggest that these analyses need to be supplemented with inhibitory mechanisms as part of the structure-building process, at least from 21-month onwards. Second, failure to identify priming effects with 21-month-olds in the current study and with 18-month-olds in other recent studies (Arias-Trejo & Plunkett, 2009; Styles & Plunkett, 2009a) suggests that a lexical-semantic network is still emerging during this period of development, and points to the possibility suggested previously by researchers (Anglin, 1970; McNeill, 1970) that early word meanings are initially represented independently of each other, albeit at a much earlier age than previously proposed. The priming boost at 21-months for words that are both associatively and taxonomically related (e.g., *dog–cat*), reported by Arias-Trejo and Plunkett (2009), indicates that these factors work together in facilitating the emergence of a lexical-semantic network. The current results suggest that independently, neither associative nor taxonomic relationships between words are adequate to activate the emerging lexical-semantic network.

It is premature to conclude, however, that younger infants do not possess the rudiments of a lexical-semantic network in which words are integrated according to their shared meaning. Mayor and Plunkett (2010) have estimated that the mean receptive vocabulary for an 18-month-old is likely to be almost 600 words. Contrast this number with the 192 candidate words used by Hills et al. (2009b) to investigate the structure of semantic networks in toddlers. The additional structure building possibilities are manifest and abundant. Although the 18-month-olds studied by Arias-Trejo and Plunkett (2009) and Styles and Plunkett (2009a) showed no evidence of semantic priming for the broad set of stimuli to which they were exposed, it remains conceivable that network structures spanning more limited semantic domains engage processes of network growth, such as preferential *acquisition* or *attachment* (Hills et al., 2009b; Steyvers & Tenenbaum, 2005), at even younger ages. Further experimental research using methods similar to those described in this paper has the potential to evaluate this possibility.

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