



Competition between multiple words for a referent in cross-situational word learning



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ABSTRACT

Three experiments investigated competition between word–object pairings in a cross-situational word-learning paradigm. Adults were presented with One-Word pairings, where a single word labeled a single object, and Two-Word pairings, where two words labeled a single object. In addition to measuring learning of these two pairing types, we measured competition between words that refer to the same object. When the word–object co-occurrences were presented intermixed in training (Experiment 1), we found evidence for direct competition between words that label the same referent. Separating the two words for an object in time eliminated any evidence for this competition (Experiment 2). Experiment 3 demonstrated that adding a linguistic cue to the second label for a referent led to different competition effects between adults who self-reported different language learning histories, suggesting both distinctiveness and language learning history affect competition. Finally, in all experiments, competition effects were unrelated to participants' explicit judgments of learning, suggesting that competition reflects the operating characteristics of implicit learning processes. Together, these results demonstrate that the role of competition between overlapping associations in statistical word–referent learning depends on time, the distinctiveness of word–object pairings, and language learning history.

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Introduction

Lexical competition is central to many phenomena in language including lexical access and on-line sentence comprehension (e.g., Allopenna, Magnuson, & Tanenhouse, 1998; Cutler, 1995; Levelt, Roelofs, & Meyer, 1999; Marslen-Wilson, 1990; McClelland & Elman, 1986; Norris, 1994). Lexical competition has also been proposed to play an important role in word learning in children and adults (MacWhinney, 1989; McMurray, Horst, & Samuelson,

2012; Merriman, 1999), and is a central mechanism assumed by models of cross-situational word–referent learning (Frank, Goodman, & Tenenbaum, 2009; Kachergis, Yu, & Shiffrin, 2012; Regier, 2005; Siskind, 1996; Smith, Smith, & Blythe, 2011; Yu & Ballard, 2007). Although there is direct evidence of competition in lexical access (Allopenna et al., 1998; Howard, Nickels, Coltheart, & Cole-Virtue, 2006; Oppenheim, Dell, & Schwartz, 2010), sentence comprehension (Bates & MacWhinney, 1989; Elman, Hare, & McRae, 2005; McRae, Spivey-Knowlton, & Tanenhaus, 1998), and in on-line word–referent disambiguation in children (e.g., Halberda, 2006; Horst, Scott, & Pollard, 2010; Markman, 1990; Merriman, Bowman, & MacWhinney, 1989; Swingley & Aslin, 2007; Yoshida, Tran, Benitez, & Kuwabara, 2011), there is no direct evidence for competition in cross-situational word–referent

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learning. Here we seek that evidence in the test of one common assumption about how that competition works: individual word–referent associations directly inhibit the pairing of other words with that referent.

The cross-situational word-learning task was designed to measure learners' abilities to find underlying word–referent pairings in the noisy co-occurrence data of heard words and seen things (Yu & Smith, 2007). The task as shown in Fig. 1a and b consists of a series of individually ambiguous learning trials in which multiple words and referents are presented with no information about which word goes with which referent. Although individual trials are ambiguous with respect to the word–referent correspondences, each object is always presented with its corresponding word such that, across trials, there is clear evidence for a single set of pairings between words and referents (see Fig. 1c). Thus, there is within-trial uncertainty, with many spurious co-occurrences between words and referents, but across-trial consistency, with the strongest co-occurrences indicating the correct word–referent pairings. Studies using this task have shown that adult learners are quite capable – even given many words and referents and after relatively few training trials – of discovering the underlying word and referent pairings from the co-occurrence statistics (e.g., Kachergis et al., 2012; Smith et al., 2011; Suanda & Namy, 2012; Vlach & Sandhofer, 2014; Vouloumanos, 2008; Yu & Smith, 2007; Yurovsky, Yu, & Smith, 2013). Even infants and children have been shown capable of learning the word–referent correspondences in these tasks (e.g., Scott & Fisher, 2012; Smith & Yu, 2008; Suanda, Mugwanya, & Namy, 2014; Vlach & Johnson, 2013; Vouloumanos & Werker, 2009). To do this, learners must attend to, store, and in some way statistically evaluate the system of word–referent co-occurrences.

A variety of algorithms, expressed as Bayesian inference models (Frank et al., 2009; Siskind, 1996), machine translation models (Yu & Ballard, 2007), or associative learning models (Kachergis et al., 2012; Regier, 2005), have been shown to be capable of discovering the underlying word–referent pairings from noisy co-occurrence data. A key property of many of these models is that potential word–referent pairings compete. Within these models, this property of the learning machinery has been shown to be critical to rapid learning (Yu & Smith, 2012) and to the learning of very large sets of words and referents (Blythe, Smith, & Smith, 2010; Reisenauer, Smith, & Blythe, 2013; Smith et al., 2011). The underlying assumption – implicit in some models, explicit in others (see Yurovsky, Yu, et al., 2013) – is that a word–referent pairing with stronger co-occurrence evidence blocks or inhibits the formation of links between other words and that referent. By this assumption, in the matrix of co-occurrences in Fig. 1c, earlier co-occurrence data between the word “modi” and object A should inhibit the later pairing of another name, e.g., “bosa”, to object A, with the resolution of this competition being a function of the relative associative strength of the two competing items. This proposed competition component in cross-situational learning is similar to competition processes found in several prominent models of word learning more generally (MacWhinney, 1989; McClelland & Elman, 1986; McMurray et al., 2012).

Such competitive processes make a strong prediction: there should be direct competition at the item level between specific words that share a referent. For example, if learners acquire one word–referent pairing strongly, learning another word for that referent should be more difficult. To date, although a variety of models that propose item-level competition have been fit to learning data, item-level competition itself has not been empirically demonstrated. The main goal of the following three experiments was to document item-level competition; a secondary goal was to determine possible limits on inter-item competition with the aim of providing potential insights as to the mechanisms or stages of learning at which competition occurs.

To these ends, we used a variant of the cross-situational word learning task shown in Fig. 1, but in our version, shown in Table 1, some referents were principally associated with one word and other referents were equally associated with two words (see also Ichinco, Frank, & Saxe, 2009; Kachergis et al., 2012; Poeppel & Weiss, 2014; Yurovsky, Yu, et al., 2013). More specifically, for the One-Word pairings, a single word co-occurred every time with its object, and the frequency and probability of these co-occurrences were much greater than the spurious co-occurrences of that object with other words (e.g., word d with object D, see Table 1). For Two-Word pairings, each object (e.g., object A) co-occurred equally and most often with two words (e.g., word a1 and word a2). Previous research has shown that these statistics should result in weaker learning of Two-Word pairings relative to One-Word pairings (Ichinco et al., 2009; Kachergis et al., 2012; Yurovsky, Yu, et al., 2013) a fact that might seem to suggest direct inter-item competition. However, the advantage of input statistics that favor One-Word pairings over Two-Word pairings may also be explained by other processes, such as differences in conditional probabilities. While some studies have attempted to control for this by manipulating the conditional probabilities (e.g., Kachergis et al., 2012; Yurovsky, Yu, et al., 2013), none have directly assessed the degree of competition among individual overlapping items. Thus, in addition to assessing overall performance on overlapping pairings as others have done (Ichinco et al., 2009; Kachergis et al., 2012; Yurovsky, Yu, et al., 2013), we assessed individual trial data at testing to obtain a direct measure of competition between overlapping pairings.

According to the principle of relative-strength competition (Desimone & Duncan, 1995; Mensink & Raaijmakers, 1988; Norman, Newman, & Detre, 2007), the degree and the resolution of competition should be a function of the relative strength of the competing items. To the extent that one pair is well learned, its overlapping competitor should be poorly learned. This is the prediction of item-level competition that is tested in the following experiments: If items directly compete, the learning of one word for an object should be negatively related to the learning of another word for that same object. Furthermore, if this competition is based on the strength of competing items, then time and the distinctiveness of individual pairings may affect the presence of competition (e.g., Estes, 1986). We tested the effect of time on competition by presenting

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