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#### **Authors**

Kucker, Sarah C.

Bagley, Aaron

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# Cascading effect of context and competition on novel word learning

Sarah C. Kucker (kuckers@uwosh.edu)

Aaron Bagley (baglea45@uwosh.edu)

The University of Wisconsin Oshkosh; Department of Psychology  
800 Algoma Blvd; Oshkosh, WI 54901 USA

## Abstract

Learning, especially in the case of language acquisition, is not an isolated process; there is ever-present competition between words and objects in the world. Such competition is known to play a critical role in learning. Namely, the amount and variability of competing items during word learning have been shown to change learning trajectories in young children learning new words. However, very little work has examined the interaction of competition amount, competition variability, and task demands in adults. The current study assesses adults' ability to map new word-referent pairs in varying amounts of competition and competitor variability. In addition, the effect of mapping context on retention was assessed. Results suggest that retention is weak in some cases and importantly, there are cascading effects of competitor variability in mapping on later retention of new words. Results are discussed in light of associative learning mechanisms and the implications of competition for learning.

**Keywords:** word learning; fast mapping; context; competition

## Introduction

Word learning always occurs in a context. New words are encountered in a conversation, new objects are alongside others on a shelf, and word-referent pairs are embedded in fleeting moments. Often, the referent for a word is not immediately clear. It is precisely this complexity and ambiguity that has puzzled researchers for decades – how do individuals, and young children in particular, correctly map a novel word to its referent amidst dozens of possible objects in the world around them? The last few decades of research have subsequently resulted in multiple pathways by which children overcome the problem of referential ambiguity to acquire new words and add them to their lexicon. We know that children appear to use their prior knowledge of objects (e.g. mutual exclusivity; Markman & Wachtel, 1988), novelty (e.g. N3C; Mervis & Bertrand, 1994), and social cues (Akhtar, Carpenter, & Tomasello, 1996) to eliminate competitors and focus on the target. We know that the number of competitors present (Zosh, Brinster, & Halberda, 2013) and the context in which objects are encountered (Horst, 2013) matter. And we know that as a child's vocabulary grows, so too does their performance in word learning tasks (Bion, Borovsky, & Fernald, 2013). There has also been parallel research on how both adults (Alt & Gutman, 2009; Greve, Cooper, & Henson, 2014; Halberda, 2006; Warren & Duff, 2014) and robots (Morse et al., 2015; Twomey, Morse, Cangelosi, & Horst, 2016) acquire new words.

Most recently, there has been a further push to view word learning as a process that unfolds over multiple timescales instead of a one-shot learning episode (Kucker, McMurray, & Samuelson, 2015). The initial mapping between a new word and its referent happens in real-time. This is an in-the-moment process of comprehending “Where’s the wif?” or “Get the dax.” However, this initial association between the word and referent is often weak and transient. Over time and repetitions the word-referent association becomes honed and strengthened, partially by reinforcing the correct links but also by pruning away incorrect associations (McMurray, Horst, & Samuelson, 2012). Regardless if it is children, adults, or robots, word learning requires real-time responses to interact with slower associative mechanisms. Successful long-term learning thus depends partially on the context in which the word-referent pair was initially encoded as well as the context in which it is stored and retrieved.

## Competition in Mapping

Across all work on word learning, there is one factor that is consistent – competition. Competition occurs between objects present in the world, between words in the lexicon, and between former knowledge and new. At times there exists a lot of competition, while at other times the competition is limited. Sometimes, the competing items that may be present are relevant and helpful (e.g. learning about forks while in the kitchen), and sometimes the competitors and context are not. In addition, the initial context in which a word is mapped to its referent can vary widely not just between people or words, but even across occurrences of a single word. That is, the word *fork* may be heard primarily in the kitchen, but occasionally could be used while outside. This competition and its variability have cascading effects on retrieval and retention of newly learned information.

One of the classic tests of word learning is Carey and Bartlett's (1978) study of “fast-mapping”. Here, preschool children were presented with a novel word while in a classroom, surrounded by multiple people and objects and tested on their ability to accurately “Get the chromium tray, not the blue one”. This referent selection task has been used for decades to test not just an individual's ability to map words and referents in ambiguous scenes, but also retain newly mapped word-referent pairs until a later time.

A critical part of the classic referent selection task is the presence of competition - in order to get the *chromium* tray, children had to decide against the *blue* tray and not pick up a cup or spoon. In many variations of the task, there is obviously competition between multiple items that may be present (e.g. tray vs. cup). Other versions of the task

highlight the competition between known items and novel (e.g. blue vs. chromium). And others try to eliminate direct competition by directly naming a single item. Regardless of the number or type of competitors, both children and adults are easily able to map a novel word to a novel referent in-the-moment (Horst, Scott, & Pollard, 2009; Warren & Duff, 2014; Greve, et al., 2014), becoming increasingly successful over development (Bion, Borovsky, & Fernald, 2013). However, real-time eye-tracking behavior does suggest there are differences in mapping due to competition. For instance, when children and adults are presented with both a known and a novel object and hear a novel word, they reliably look to the competing known items before settling on the novel referent (Halberda, 2006). In addition, there is evidence that explicit selection of a competitor (in error) can still lead to later learning (Fitneva & Christiansen, 2011). Thus, the simple presence of competitors can change even subtle selection behaviors and cognitive processing.

Furthermore, other work suggests that the details about how many competitors or the variability of the competitors also shift real-time processing, which has cascading effects on long-term learning. First, work with children suggests that the number of competitors present during mapping has a direct negative correlation on performance – fewer items seem to help mapping (Axelsson, Churchley, & Horst, 2012), but more competitors benefit long-term learning (Zosh, et al., 2013). And, computational models of referent selection and retention propose that though more competition during mapping requires more cognitive processing, it also results in more opportunities for pruning away spurious word-referent links, thus allowing more honing in a single trial (McMurray, et al., 2012). This subsequently boosts retention (McMurray, Zhao, Kucker, & Samuelson, 2013). In a recent study of adult word learning, encoding new words with competitors resulted in almost immediate lexical competition between the new word and known word. However, learning that occurred in an isolated, direct-naming context did not (Coutanche & Thompson-Schill, 2014). Competitive initial learning also led to broader semantic networks days later. Taken together, the amount of competition influences real-time processing and has cascading effects on long-term retention.

In addition to the amount of competition present, the type of competition may also play a role. Specifically, the relevance and variability of competing known foil items interacts with new word-referent pairs. Recent work has demonstrated that young children often learn new words better when couched in a known context, such as when drawn from a category of objects they are familiar with (Borovsky, Ellis, Evans, & Elman, 2016), or when an item is physically located in a related scene (Meints, Plunkett, Harris, & Dimmock, 2004). It is also clear that both children and adults pay attention to competitors even if they are not the target. In some cases, children implicitly extract some minor representation or memory for competitors such that they are more likely to look at them later (Wojick, 2013). In other cases, adults recall semantic information about the

novel target, acquired while the target was presented in various scenarios (Alt & Gutman, 2009). In addition, context diversity is more predictive of word knowledge in adults (and vocabulary acquisition in children) than simple frequency of occurrence (Adelman, Brown, & Quesada, 2006; Hills, Maouene, Riordan, & Smith, 2010). Put together, this suggests that the composition of, and specifically the relationship between, the competitors might matter not just for mapping, but also for retention.

## Competition in Retention

Generally, adults are considered to be good at learning new words, performing well above chance on laboratory tasks (Greve, et al., 2014). However, we also know that an individual's ability to retain newly learned words is reliant on a number of factors, such as the length of delay (Vlach & Sandhofer, 2012; McGregor, 2014) and phonological neighbors (Tamminen & Gaskell, 2008). Work with children has suggested that retention is also partially dependent on the number of competitors present during mapping (Zosh, et al., 2013), and the types of cues present during encoding (Capone & McGregor, 2005). Furthermore, most work showing good retention with adults has thus far primarily used relatively easy task – pulling the target out of a three-item array. Thus, though adults are expected to be good at learning new words, it is likely that competition can still play a role. A recent study by Dautriche and Chemla (2014) found context effects in cross-situational learning where consistent repetition of competitors over the course of multiple blocks led to improvements in memory for both the broader context group and target. Learning here was tested through forced-choice selection of the target from four-item array. In another study, Warren and Duff (2014) tested retention after a zero competitor/ ostensive (direct) naming condition as well as a two-item referent selection condition. Critically, they looked at retention with both a three-alternative forced-choice recognition test (3AFC) and free recall (recalling word-forms from test). Overall, typically developing adults selected the referent on the 3AFC test well above chance, near 65% correct, for both conditions. However, free recall varied between the mapping contexts - accuracy was higher for words learned directly without competitors than those with competition during mapping. That is, though context may influence initial encoding, the method for tapping retention is critical in assessing the robustness of the newly acquired word-referent pair.

Despite the lack of work on competition effects on the retention of new words, the evidence suggests that the associative learning processes of adults, like children, are highly variable and occur incrementally over multiple timescales (Kucker, et al., 2015). Such associative processing occurs over the lifespan and critically, some propose that the complex networks in which new words are learned are also linked with advances in other areas of cognition (Roembke, Wasserman, & McMurray, 2016). Thus, the process of learning a single new word has

important implications for broader theories of associative learning and cognition.

### Current Study

Competition is widely accepted as highly relevant for word learning, but there is still much debate about how much competition is optimal and what effects initial competition has on long-term learning. Both the number and variability of competitors has been studied in word learning of young children (though with mixed results); much less work has been conducted in adults despite the fact that adults too, continue to learn new associations. In addition, the question of how adults learn simple associations (such as words) is at the crux of many computational models of learning and information processing (e.g. Regier, 2005; McMurray, et al., 2012). Thus, there is a gap in understanding both how an adult’s real time processing changes across contexts and the impact the contexts have on their retention of new word-referent associations. The current study fills this gap by combining word learning methods from work with children with the adult literature to test the impact of competition (amount and variability) on in-moment mapping, and the cascading effects mapping context has on retention. Furthermore, learning is assessed with two different methods to tap both weak associations that may be recognized in an array but not recalled as well as robust associations that can be easily recalled without cues.

## Methods






### Participants

A total of 149 adults participated. All individuals were monolingual English speakers and provided informed consent before participating. Individuals were recruited either through a current college course (receiving course credit), or through Amazon’s MTurk (receiving \$1.75).

### Stimuli

Individuals saw a randomly selected subset of known and novel words and objects over the course of the experiment. Known items were drawn from pools of prototypical toys (book, ball, drum, block), kitchen utensils/tools (fork, spoon, bowl, cup), vehicles (car, boat, airplane, bike), clothing (shoe, hat, belt, purse), or furniture (chair, bed, lamp, clock). All images were previously normed by a separate set of adults to elicit their respective labels and be obvious members of their category. Novel items were drawn from a pool of unique items typically used in child word learning studies. These items were judged in prior studies to be highly unfamiliar and not easily named by most adults (Horst & Hout, 2016). Novel words were legal words in English but had few or no known orthographic neighbors.

Table 1. Mapping conditions

Condition	# of Competitors	Example trial
		“Which is the <i>cheem</i> ?”
OD none	0	
3AFC vary	2	
5AFC vary	4	
3AFC same	2	
5AFC same	4	

and all completed the entire study on-line in a single sitting. Conditions varied in the number of competitors present during initial mapping and the variability of competitors present (Table 1). The number of competitors varied from zero to four with the to-be-learned novel object present alongside no other items (ostensive definition trial; OD none), paired with two distinct known competitors (3 total items, alternative forced-choice trial; 3AFC), or paired with four distinct known competitors (5AFC) on each trial. Competitors also differed in their variability – competitor items were either variable, drawn from distinct known categories (vary), or clustered and drawn from the same category (same).

Each condition began with a mapping phase in which participants were initially exposed to novel word-referent pairs, followed by a retention phase in which they were tested on their memory for the word-referent pairs from mapping. During the mapping phase, participants were instructed to pay attention to a series of word-referent pairs presented on the screen. One each trial, a novel printed word was presented along with an image of a novel object. In the OD none (0 competitions) condition, no other items were present on the screen. In the 3 and 5 item conditions (3AFC, 5AFC), 2 or 4 images of known items were respectively presented alongside the novel item. Items were presented equally spaced in a horizontal row with location randomized across trials. In each case, the participant had to click on the correct referent before proceeding to the next trial. Novel word-referent pairs were presented at least once (in the case of OD none) and no more than three times (for most AFC versions) over the course of all training trials (referred to as Novel Mapping trials). The 3AFC and 5AFC conditions also included filler/catch trials in which participants were asked to select one of the known items (referred to as Known Mapping trials). These were included both as catch trials and to draw the participants attention to the competitors in order to increase encoding of them. There were between 12 and 16 total mapping trials and each participant was trained on 4-5 novel words.

Immediately following the mapping phase, participants were tested for their comprehension and retention of the novel word-referent pairs. This was done via two methods – free response recall and forced-choice (multiple choice) recognition. The free response retention trials asked participants to describe the referent for each of the novel words from mapping/training (e.g. “Describe the cheem”). Though prior work has asked participants to recall the word-form (thus testing phonological memory), here we ask for a description of the item to tap semantic-conceptual memory and thus allow a tighter connection to what is tested in the forced-choice trials. In addition, one current hypothesis is the semantic relationship (not names) between stimuli matters. In the forced-choice trials, participants were given one of the novel words from mapping and asked to select the correct referent from an array of all multiple novel objects from mapping. Words and objects for all phases were counter-balanced across conditions and participants.

## Results

Average percent correct for each participant on Known Mapping trials, Novel Mapping trials, Forced Choice (recognition) Retention, and Free Recall Retention were scored. Both Mapping trials and the Forced Choice Retention were calculated as percent of trials an individual correctly chose the target. Free Recall response was scored by 2-3 independent, blind coders who calculated a binomial score for each answer. If the written description was specific enough to uniquely identify the target object from the array of novels, it received a score of one. However, if the description was either too vague to refer to a single specific item or if it described a foil object, it received a score of zero. This coding scheme thus gave participants credit for a variety of responses (e.g. an overall description or a single unique feature) as it eliminated possible referents systematically based on the information given. For instance, if the participant responded “the blue flat thing”, and there was only one novel item presented that was blue (and it was the correct answer), they would receive a one. If, however, a participant responded with “the round one”, and multiple novel objects were spherical, then they would receive a score of zero. Only scores of one were counted as correct in calculating overall performance. All coding was conducted as a consensus of scores across two blind coders with additional 1-2 coders settling all discrepancies. Responses that required more than four coders to come to a consensus were thrown out.

First, performance on mapping across all conditions was analyzed. Each condition was compared against chance and each trial type was analyzed with a two-way ANOVA of performance on Number of Competitors (3AFC vs. 5AFC) by Competitor Type (vary vs. same). Unsurprisingly, adults are very good at the Known item filler trials on all conditions, selecting the known target item at nearly ceiling levels (see Figure 1). As suspected, there was no difference between conditions on these trials (Known Mapping;  $F(1,149)=.806, p=.493, \eta^2=.016$ ). Adults were also well

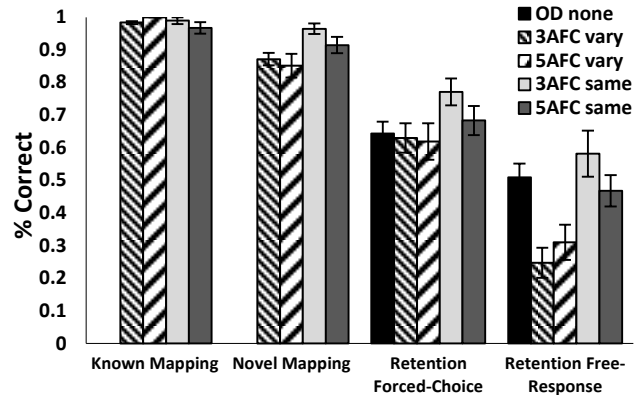


Figure 1. Performance on mapping and retention

above chance in all conditions at selecting the novel target (Novel Mapping). However, there was a main effect Type of Competitors,  $F(1,178)=9.027, p=.003, \eta^2=.048$ , with adults performing significantly better when the competing items varied than when competitors were from the same category. There was no effect of competitor amount. This suggests that despite a very robust lexicon and a clear ability to find the referent when asked, adults real-time mapping of novel words may be influenced by subtle changes in the type of items present, regardless of the number of items.

Performance on retention was then analyzed. Most subjects were asked both a free recall retention question followed by a forced-choice recognition test. Due to a programming error, 29 subjects in the 3AFC same condition only answered the forced-choice test and 24 subjects in the 3 varies condition were asked the forced-choice first followed by free recall.<sup>1</sup> In addition to testing performance against chance, a repeated measures ANOVA of Retention Test Type (forced-choice vs. free recall) on Number of Competitors (3AFC vs. 5AFC) by Competitor Type (vary vs. same) was run. First, adults were well above chance in all conditions on the forced-choice retention, though importantly, not at ceiling. Chance in both cases was set at 20% as presumably, adults were recalling one of the five just-learned items. On free recall, however, performance was much more mixed with performance in the vary conditions at or near chance, 3AFC:  $t(45)=1.401, p=.168$ ; 5AFC:  $t(28)=2.042, p=.051$ . In addition, there was a significant ANOVA of Retention for Type of Retention, Number of Competitors and Competitor Type,  $F(1,216)=5.865, p=.016, \eta^2=.026$ , with a significant Competitor Type main effect,  $F(1,216)=13.286, p<.001, \eta^2=.058$ , and Test Type by Competitor Type interaction,  $F(1,199)=5.655, p=.018, \eta^2=.028$ . Thus, the variability of the context matters for mapping *and* has cascading effects on retention, especially when a more rigorous test of recall is used.

<sup>1</sup> There was a marginal effect of order; Forced Choice (FC) Retention before Free Recall (FR) led to higher Retention (FC:  $t(46)=2.38, p=.021$ , and FR:  $t(44)=1.88, p=.067$ ). However, main effects and interactions in the overall ANOVA remain the same with and without order included.

## Discussion

Overall, the results show a unique pattern of responding for both in-the-moment mapping as well as retention. Though the type of competitors appears to matter overall for Novel Mapping, its effect on retention is confounded by the type of test, showing differential affects for forced-choice vs. free response retention. This could mean that the processes that support real time processing may not be the same mechanisms driving retention. Alternatively, it could suggest that associative learning is a complicated interaction of multiple factors and tasks and there are different ways of tapping knowledge to reveal those processes in different ways. That is, a free response retention test has no other items present. Thus, in order to respond, an individual has to have a robust memory to retrieve, but also may grasp onto any cues they can, such as vague memories from when they initially learned the word (Coutanche & Thompson-Schill, 2014). Initial context that had more helpful cues (similar, same competitor condition) would give more relevant aids to retrieval, thus boosting performance.

Not only does the type of test matter, but subtle shifts in learning that are not always apparent with one test can be revealed with another. Specifically, the different retention tests give hints to the strength of the word-referent associations formed. Forced choice retention tests show only a slight effect of competitor variability, however, free recall for those exact same items is influenced in a different way by the variability of competitors from the previous mapping trials - variable competitors are equivalent to the Ostensive Naming, zero competitors condition on forced-choice retention, (though lower than same competitor condition) but at chance when tested with free recall (at which point all other conditions are above chance).

These results also speak to the nature of the underlying association. During mapping, the initial association is weak, fragile, and likely has many spurious connections. More competitors, especially competitors that are vastly different and unique, take longer to process, and thus initial mapping is less successful. In some prior cases, these “harder” initial encoding scenarios have led to more robust learning because they require more processing (Vlach & Sandhofer, 2014). If we only test learning through a forced choice recognition test, that is precisely what we see – above chance learning across the board. However, the free response retention reveals that the variable groups (the same groups who were relatively poorer on Novel Mapping) are at chance for recalling the word-referent link. This suggests that the word-referent link that is being built during mapping has clearly been encoded and withstands weak tests of its viability, but has a long way to go before it is fully integrated into the lexicon.

At its core, word learning is a form of associative learning. As such, the results of the current study may suggest that domain-general associative mechanisms are influenced by the context and competition. Importantly, associations are constantly in flux and robust links are not guaranteed, even in supposedly “easy” cases of learning.

That means that the imperfect retention seen in the current study is not evidence for a lack of learning, but rather as an in-progress process which will continue to be strengthened over time. The type of competitive mechanism employed in these associative learning situations is not just beneficial for a single moment as demonstrated here, but likely also beneficial for the 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> and all future encounters of the word (Benitez, Yurovsky, & Smith, 2016; Dautriche & Chemla, 2014; Yurovsky & Yu, & Smith, 2013). That is, learning is reliant not just on one-to-one links, but rather is couched within a larger network which has a direct influence on the development of a single association, which in turn may alter learning future associations.

As a whole, the current study examines two critical elements to associative learning – 1) how does the amount and variability of context shape real-time processing, and 2) how does the amount and variability of the competitors shape the refinement of those associations over time. Results suggest that there is not a single pathway to mapping or retaining, but rather, like most cognitive processes, it is a complicated interaction.

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