When is Four Far More Than Three? Children's Generalization of Newly-Acquired Number Words

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When is *four* far more than *three*?
Children's generalization of newly-acquired number words

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Abstract

What is the relationship between children's first number words and number concepts? We used training tasks to explore children's interpretation of number words as they acquired their meanings. Children who had mastered the meanings of only the first two or three number words were systematically provided with varied input on the next word-to-quantity mapping, and their extension of the newly-trained word was assessed across a variety of test items. Children who had mastered number words to *three* generalized training on *four* to new objects and nouns, with approximate accuracy. In contrast, children who had mastered only *one* and *two* learned to apply *three* reliably within a single count noun context (*three dogs*) but not to new objects labeled with different nouns (*three cows*). Both findings suggest that children fail to map newly-learned words in their counting routine to fully abstract concepts of natural number.

Key words: counting, word learning, numerical concepts, cognitive development

The relationship between number words and concepts has drawn substantial attention from cognitive and developmental psychologists in light of two curious observations (Gelman & Gallistel, 1978, 2004; Wynn & Bloom, 1997; Dehaene, 1997; Mix, 2002; Carey, 2009). First, children learn the verbal counting list before they understand that number words pick out specific, unique and exact cardinal values (Condry & Spelke, 2008; LeCorre & Carey, 2007). Second, children learn number-word meanings very slowly (Wynn, 1990, 1992a), in contrast with many other kinds of words (e.g., Carey, 1978). When asked for a specific number of objects (the "Give-N" task), most 2-year-old children produce one object when asked for *one* but produce no consistent amount when asked for larger numbers ("one-knowers"). By 2.5 years, most children give two objects when asked for *two* but grab a handful for larger quantities ("two-knowers"). Several months later, children respond appropriately to *three* ("three-knowers") and by their fourth birthday, most children master the logic of verbal counting.

What hypotheses do children entertain in learning the meanings of number words? From the start of number-word learning, children might hypothesize that each number word maps onto an abstract numerical magnitude (Gelman & Gallistel, 1978; Dehaene, 1997; Wynn, 1998). Thus a child who is taught the meaning of *two* in one context would apply the word to any set of two individuals regardless of their kind. This possibility gains plausibility from findings that infants show capacities to enumerate visible objects, sounds, and actions (see Feigenson, Dehaene & Spelke, 2004) and detect numerical correspondences between sets of objects and sounds (Izard, Sann, Spelke & Streri, 2009; Jordan & Brannon, 2006). Alternatively, children might initially learn more narrow number-word meanings: a child who learns *two* in one context (e.g., *two dogs* applied to a set of two dogs) may extend the word only to objects (e.g., to pairs of horses but not sounds or actions) or only to entities named by the same count noun (i.e., to other dogs). This second possibility is consistent with findings demonstrating that children often fail to apply number words broadly across distinct contexts (Mix, Huttenlocher & Levine, 1996; Mix, 1999; Mix, 2002).

The present research attempts to tease apart these two accounts of early number-word meanings by exploring children's interpretation of newly-trained number words. Training paradigms have been used productively to probe children's mapping of concepts onto adjectives and spatial terms (Kiblanoff & Waxman, 2000; Shusterman & Spelke, 2003). They may be particularly useful for studying number-word learning because they can reveal intermediary conceptual representations during the acquisition process (Siegler, 2007; Griffin & Case, 1996). In three experiments, we trained children who have mastered number words up to *two* or *three* on the next word in their count list, under controlled conditions. We then asked what meanings children attributed to these words by assessing their generalization of the trained word to new entities and new linguistic contexts.

Experiment 1

In Experiment 1, we trained two-knowers and three-knowers on the next word-to-quantity mapping (*three* or *four)*, using pictures of animals as training stimuli. Then we tested for a very limited form of generalization: could children extend the trained word to pictures of different animals?

Methods

Participants. All children were monolingual English-speakers and were accompanied by a parent. From a sample of 38 children, 16 children were categorized as two-knowers (2;6-3;6, M=3;2, eight boys) and 16 were categorized as three-knowers (3;2-3;9, M=3;7, eight boys) on the Give-N task. The remaining children were categorized as one-knowers or four-knowers and were not tested further.

Counting: Children were given 10 objects and encouraged to count them. All children produced the count list to *ten* without error.

Give-N task: Children then were shown small plastic fish and were asked to put different quantities from *one* to *six* into a basket (*"Can you make ___ fish jump into the pond?"*). The experimenter began by asking for *one fish* and continued onto higher numbers in a pseudo-random order. When children failed to produce a quantity correctly (e.g., *four*), the experimenter asked for the number directly below (i.e., *three*) before returning to the incorrect number. If children produced the correct quantity in one instance but an incorrect one in the other, they were asked for the number a third time to determine their maximum level of reliable knowledge. Children were assigned to a training condition based on their knower level.

Two-knower training: During training, two-knowers were shown cards depicting eight different kinds of animals. First, they saw two trials where a single card featuring three animals was labeled with a count phrase (*"This card has three cows!"*). Next, they were shown six trials where a card with *three* was contrasted with a card depicting another quantity (*"This card has three birds! This card does not have three birds!"*). These contrasts included numbers that the children had mastered (1 or 2) and numbers they had yet to master (4, 5, 6, or 10). These sets varied in their spatial arrangement (lines vs. triangles) but presented objects of constant size and shape. Thus continuous variables such as summed area and summed contour length were correlated with number. In the final phase of training, children were given the same card pairs again and were asked to select the one with three items (*"Can you give me the card with three birds?"*). Errors were infrequent and were corrected.

During the test phase, two-knowers were shown ten new card pairs each featuring new kinds of animals and were asked to select one card using a number word. On two trials (known-known), the card pairs contrasted two known quantities (1 vs. 2: *"Can you give me the card with two horses?"*). On four further trials (trained-known), a card with three animals was paired with a known quantity (3 vs. 1 or 2). On the four critical trials (trained-unknown), a card with three animals was paired with a quantity children did not have a word for (3 vs. 4, 5, 6, or 10). In both cases, children were asked for *three* (*"Can you give me the card with three pigs?"*). To discourage responding on the basis of non-numerical information, the paired test cards varied both the arrangements and the sizes of the items such that the two quantities were matched for total continuous extent (e.g., three large chickens vs. five smaller chickens).

Three-knowers: The procedure and controls were identical, except that children were trained and tested on *four*. The known numbers in training and test were 1-3 and the unknown numbers were 5, 6, 10, and 16.

Results and Discussion

Preliminary analyses revealed no effects of gender in any experiment. All analyses therefore collapsed over this variable.

Two-knowers. Two-knowers performed well on known-known trials, 89%, $t(15)=7.01$, $p<.001$, $d=3.62$, and trained-known trials, 91%, $t(15)=8.06$, $p<.001$, $d=4.16$, but they performed at chance on the critical trials contrasting *three* to an unknown number, 47%, $t(15)=0.44$, $p>.60$, $d=.23$. A one-way ANOVA revealed a significant difference across the trial types, $F(2,30)=17.02$, $p<.001$, $\eta^2=.53$. Performance in the known-known and trained-known conditions did not differ ($p>.80$) and was significantly better than in the trained-unknown condition (both p's<.01). In the trained-unknown condition, there were no reliable differences in performance across the different comparison quantities ($p>.30$).

The failure of two-knowers to generalize on the critical trials contrasts with their consistent selection of the correct cards during the final phase of training. It is unlikely that this discrepancy reflects a memory failure, because the transfer test immediately followed training. Instead, it suggests that two-knowers employed one of two strategies. First, they may have mapped *three* onto the exact features of the corresponding training card, without extracting a more general relation between *three* and a numerical value. Alternatively, children's generalizations may have been restricted to particular count nouns (or object classes) which were evaluated as a single unit during the training phase (e.g. *"three dogs"* or *"three fish"*). Experiment 3 explores these possibilities.

Three-knowers. Three-knowers performed at ceiling on known-known trials, 100%, $W=136$, $Z=3.49$, $p<.001$, and well above chance on trained-known trials, 84%, $t(15)=7.86$, $p<.001$, $d=4.06$, and trained-unknown trials, 71%, $t(15)=3.77$, $p<.01$, $d=1.95$. Nevertheless, there were reliable differences between the three trial types, $F(2,30)=12.25$, $p<.001$, $\eta^2=.45$. Performance for known-known trials was higher than the two conditions with the trained number (p's<.001), which did not differ ($p>.10$).

The performance of three-knowers on the critical trained-unknown trials was influenced by the numerical magnitude of the contrasting array, $F(3,45)=4.03$, $p<.05$, $\eta^2=.21$ (see white bars in Figure 1). They reliably selected 4 when it was paired with 10 or 16 ($p<.01$) but not when it was paired with 5 or 6 ($p>.30$). Children's failure to select the card with 4 objects over that with 6 objects is striking, because infants can discriminate between arrays of 4 and 6 objects on the basis of number (Xu & Arriaga, 2007). It suggests that children mapped the newly-trained word *four* onto a highly imprecise representation of number.

INSERT FIGURE 1 ABOUT HERE

Thus, from this brief training procedure three-knowers were able to extract an interpretation of *four* which generalized to new sets of animals (and new count nouns). Experiment 2 investigates whether three-knowers will generalize *four* more broadly still, from pictured animals to solid artifacts.

Experiment 2

Three-knowers were familiarized with the meaning of *four* using the same card-pair training procedure, but they were tested with sets of concrete, household objects. The test objects therefore differed from the training stimuli in both their spatial and tactile properties and their ontological status (animals vs. artifacts). If children's initial interpretation of *four* is sufficiently abstract, it should generalize across these features and their performance should be equivalent to Experiment 1. If children's notion of the next word-to-quantity mapping is restricted to a more narrow conceptual domain (i.e., animals) or to more superficial properties of the exemplars (i.e., pictures), then generalization in Experiment 2 should be less robust.

Methods

From a sample of 29 children, we selected the first 12 children who counted to *ten* and were categorized as three-knowers (3;1-3;10, M=3;6, seven boys) on the Give-N task.

The training method was identical to that used for three-knowers in Experiment 1. Children were tested with seven sets of objects (e.g., coins, pencils) pasted onto cardboard panels. They received trained-known and trained-unknown trials, following the procedure of Experiment 1 and using the same contrasting quantities (5, 6, 10, and 16). On the critical trained-unknown trials, the paired sets of objects were approximately matched in surface area (e.g., 4 large vs. 10 small legos).

Results and Discussion

After training, children successfully selected *four* objects on trained-known trials, 86%, $t(11)=7.39, p<.001, d=4.46$, and trained-unknown trials, 70%, $t(11)=2.69, p<.05, d=1.62$. Children performed as well as in Experiment 1: An ANOVA with Experiment and Trial type as factors revealed better performance when *four* was paired with a known than an unknown number, $F(1,26)=6.47, p<.05, \eta^2=.20$, but no main effect of Experiment or interaction across the experiments (p's>.60).[1] Thus three-knowers acquired a word-to-quantity mapping for *four* that generalized from pictures to concrete objects.

The performance of three-knowers on the trained-unknown trials again was influenced by the numerical magnitude of the contrasting array, $F(3,33)=2.95, p<.05, \eta^2=.26$ (see dark bars in Figure 1). Children reliably selected 4 when it was paired with 10 or 16 ($p<.05$) but not when it was paired with 5 or 6 ($p>.20$). Experiment 2 therefore replicates the finding, from Experiment 1, that children generalize the newly-trained word *four* to nearby but discriminably different numerosities.

In summary, three-knowers successfully generalized *four* not only to novel pictures of animals but also to three-dimensional artifacts. By the time children become three-knowers, therefore, their initial interpretation of a new number word is fairly broad. Children's greater success on test pairs with larger numerical differences suggests, nevertheless, that these initial number-word meanings are imprecise.

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[1] The comparison between the experiments had sufficient power to detect a moderate effect of stimulus type ($\lambda=.80$ for mean difference=16%, collapsed across the trial types).

Next we return to the mysterious performance of the two-knowers in Experiment 1. Did the children's success in the training phase and failure in the test phase, arise because they memorized the training cards, or because their generalization of *three* was restricted to particular object kinds, designated by particular noun phrases?

Experiment 3

Experiment 3 tested whether two-knowers' initial interpretation of *three* is restricted to particular lexical or conceptual contexts. Young children's interpretation of newly-learned adjectives shows just this pattern of conservative generalization. When 3-year-olds hear a bumpy horse described with a novel adjective ("*a very blickish horse"*), for example, they successfully generalize *blickish* to other bumpy horses but not to animals from different basic-level categories such as bumpy rhinoceroses (Klibanoff & Waxman, 2000). Perhaps children's initial meanings for number words are similarly restricted. To explore this question, we compared two-knowers' generalization of a trained number word to novel test materials from either the same category or a different category.

Methods

From the same sample as in Experiment 2, we selected the first 16 children who counted to *ten* and were categorized as two-knowers (2;3-3;5, M=3;1, nine boys) by the Give-N task.

During training, two-knowers saw multiple target cards presenting the same picture of three small dogs arranged in a triangle. These target cards were paired with larger sets of dogs (3 vs. 4, 5, or 10), and both were labeled with respect to the trained number ("*This card has/does not have three dogs!"*). Following this demonstration, children again were presented with the same card pairs and asked to select the one with the trained number. Errors were infrequent and were corrected.

During test, children were presented with 12 card pairs in which the target was presented with a higher, unknown number (4, 5, or 10). There were four trial types with different kinds of target card: (1) the original target (small dogs in a triangle), (2) the target set transformed in size and spatial configuration (large dogs in a row), (3) different target objects from the same basic-level kind (dogs of a different breed in a triangle), and (4) animals from a different basic-level category (small sheep in a triangle). In all cases, the distractor card contained items of the same kind and size as the target card, in a different configuration. For the first three trial types, children were asked for the card with *three dogs*. For the fourth, they were asked for the card with *three sheep*. The four trial types were blocked and the presentation order of each block was randomized between subjects.

Results and Discussion

A one-way ANOVA revealed a significant difference in children's performance across the four trial types, $F(3,45)=7.09, p<.01, \eta^2=.32$ (see Figure 2). While children performed equally well on the original target, size/space variant, and within-category variant trials (all p's>.40), they performed significantly less well on the between-category variant trials (all p's<.01). Children reliably identified *three* when presented with the original target cards, $t(15)=4.88$,

$p<.001, d=2.52$, new cards in which the targets changed in size and spatial arrangement, $t(15)=6.78, p<.001, d= 3.50$, and new cards depicting objects from a different subordinate class within the same basic-level kind, $t(15)=6.00, p<.001, d=3.10$. However, children were at chance when the cards depicted animals from a different basic-level category, $t(15)=0.68, p>.50, d=.35$. These findings provide evidence that two-knowers' initial interpretation of *three* is limited with respect to the particular category and/or noun that is quantified.

INSERT FIGURE 2 ABOUT HERE

Collapsing across the four trial types, we again found no effect of numerical distance on correct card selection ($p>.60$; see Figure 3).[2] Unlike three-knowers, two-knowers did not appear to map the meaning of their trained number word to an approximate numerical magnitude. Instead, they learned to apply *three dogs* to arrays of exactly three dogs, regardless of their size, spatial configuration, or breed.

INSERT FIGURE 3 ABOUT HERE

General Discussion

Three experiments explored children's hypotheses about the meanings of new number words. Our findings highlight two striking patterns. First, children who had mastered the meanings of number words up to *three*, acquired a fairly broad understanding of the meaning of *four* after training under restricted conditions. When they were shown that *four* applied to pictured sets of animals, they readily generalized the word to new kinds of animals and even to solid artifacts. These children, however, generalized *four* in an approximate manner in both experiments, applying the word to sets of 5 or 6 objects despite contrastive training with these numbers. This pattern is unlikely to stem from counting errors: our children did not count out loud in either the Give-N task or in the test phase. Furthermore, counting errors would be expected to produce a generalization gradient around the correct value of 4, and not categorical rejection of 3 with acceptance of 5 and 6. Instead, children's performance suggests that they mapped the trained word onto an approximate numerical representation like that found in animals, infants, and adults across diverse cultures (Feigenson et al., 2004).

Second, children who had mastered the meanings only of *one* and *two* were extremely limited in their generalization of *three*. When trained on multiple kinds of animals, they showed no generalization to new kinds of animals. Moreover, when trained on a single kind of animal presented in a single configuration (*three dogs* in a small triangle), they learned to apply *three* to arrays of dogs of novel sizes, spatial arrangements, and breeds but not to arrays of sheep. The limited performance of two-knowers is surprising: these children counted reliably to *ten*, producing words like *three* in the same contexts in which they produced *one* and *two*. Two-knowers also apply *one* and *two* to diverse entities including both objects and actions (Wynn, 1990). Finally across all knower-levels, children's ability to produce a particular number of sounds is strongly predicted by their performance in the Give-N task with objects (Huang, Snedeker, & Spelke, 2005). Nevertheless, two-knowers' narrow generalization of *three* post-

[2] Note that an effect of the size observed in three-knowers (mean difference=34%) would have been detected with virtual certainty ($\lambda=.97$).

training suggests that their understanding differs qualitatively from that of three-knowers or adults.

This pattern of limited generalization lends itself to two distinct explanations. First, two-knowers may initially map the entire quantified phrase (*three dogs*) to a holistic representation of its meaning. In linguistic theories, numbers do not have referents, they are functions that take nouns to yield quantified phrases (which may have referents). To extract the number's meaning from this semantic structure, the child might have to learn several such phrases to isolate the common element. Too much input variability could prevent the initial holistic mappings, too little could hinder subsequent re-analysis.[3] This hypothesis is consistent with research highlighting the importance of linguistic context, and nouns in particular, in the acquisition of adjectives and verbs (Gillette, Gleitman, Gleitman, & Lederer, 1999; Waxman & Booth, 2001).

Second, two-knowers may extract the number word from the phrase but initially map it to a representation that includes information about basic-level object kinds. A numerically-relevant representation with precisely this property has been proposed to account for infants' ability to track objects over movement and occlusion (see Xu & Carey, 1996). This "object file" system has an early capacity limit of 3 (Wynn, 1992b; Feigenson, Carey, & Hauser, 2002; Wood & Spelke, 2005) and consequently could provide possible meanings for *three* but not *four* during number-word acquisition. Moreover, it expresses quantities only implicitly in terms of individuals and their properties: an array of two dogs is expressed as [DOG, DOG] by this system. Thus two-knowers who mapped *three* to the representation [DOG, DOG, DOG] could infer that the term only applies to cases involving these individuals. This hypothesis is consistent with the centrality of basic-level concepts in young children's cognition (Rosch & Mervis, 1975).

In contrast, the three-knowers' approximate generalization of *four* suggests the use of a second conceptual system which represents larger approximate magnitudes. This system supports infant computations of large quantities across sensory domains (Brannon, 2002; Xu & Spelke, 2000; Lipton & Spelke, 2002; Wood & Spelke, 2005) and guides children's understanding of number words before they learn verbal counting (Wagner & Johnson, 2009; Shusterman, Carey, & Spelke, 2009). The set size limit on object file representations might lead children to shift from one representational system to the other between *three* and *four*, allowing three-knowers to entertain a broader hypothesis about the scope of the next word-to-quantity mapping. However, this system does not provide exact representations of numerosity (Dahaene, 1997), so children would generalize the newly-learned word *four* to nearby magnitudes.

The present findings may lend insight into the slow pace of children's number-word acquisition. In the absence of a single system of exact numerical representation, children cannot simply map number words onto existing concepts. Instead they have to create a conceptual representation that goes beyond either of the two supporting systems (Carey, 2009). Further studies using the present training methods may help to specify how children construct this new conceptual representation.

[3] Thus the two-knowers in Experiment 1 may have failed either to make the initial narrow mappings because of input variability or an inability to extend the mappings they made to novel kinds or nouns.

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Figure Captions

Figure 1. In Experiments 1 and 2, the proportion of correct card choices across four ratios by three-knowers.

Figure 2. In Experiment 3, the proportion of correct card choices for four trial types by two-knowers.

Figure 3. In Experiment 3, the proportion of correct card choices across three ratios by two-knowers.

Figure 1

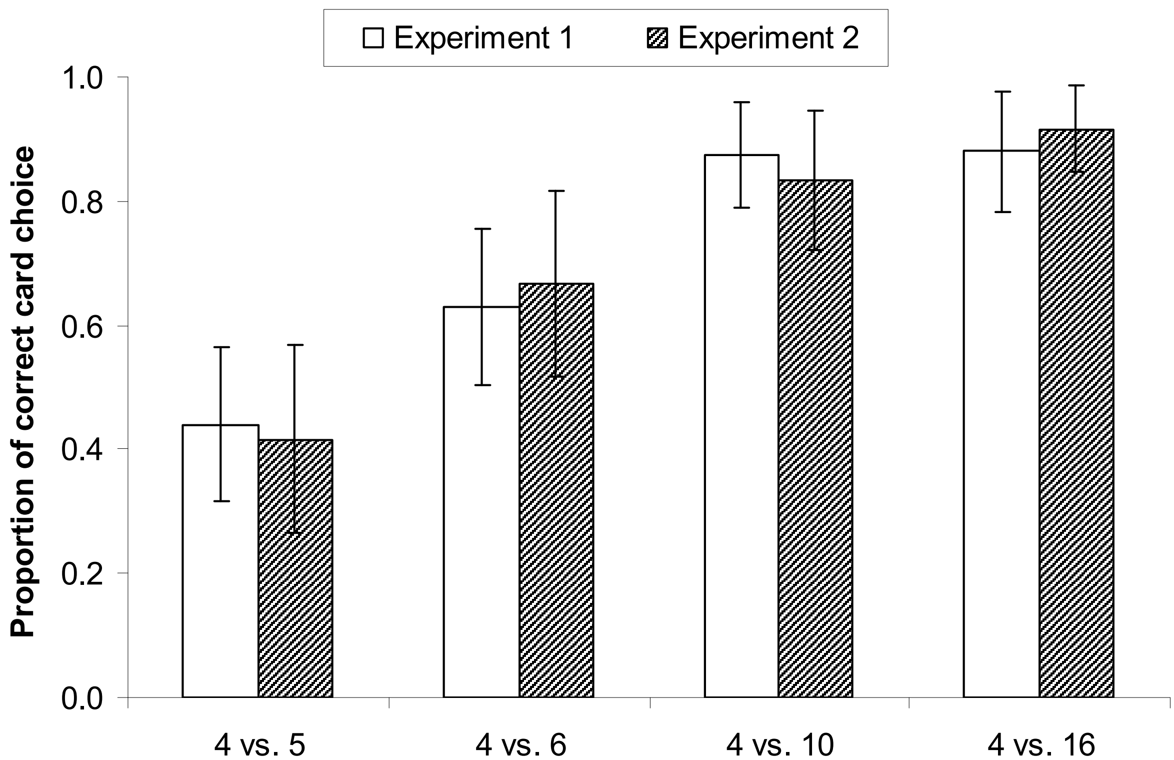

Experiment 1
Experiment 2
1.0
0.8
0.6
0.4
0.2
0.0
Proportion of correct card choice
4 vs. 5
4 vs. 6
4 vs. 10
4 vs. 16

Figure 2

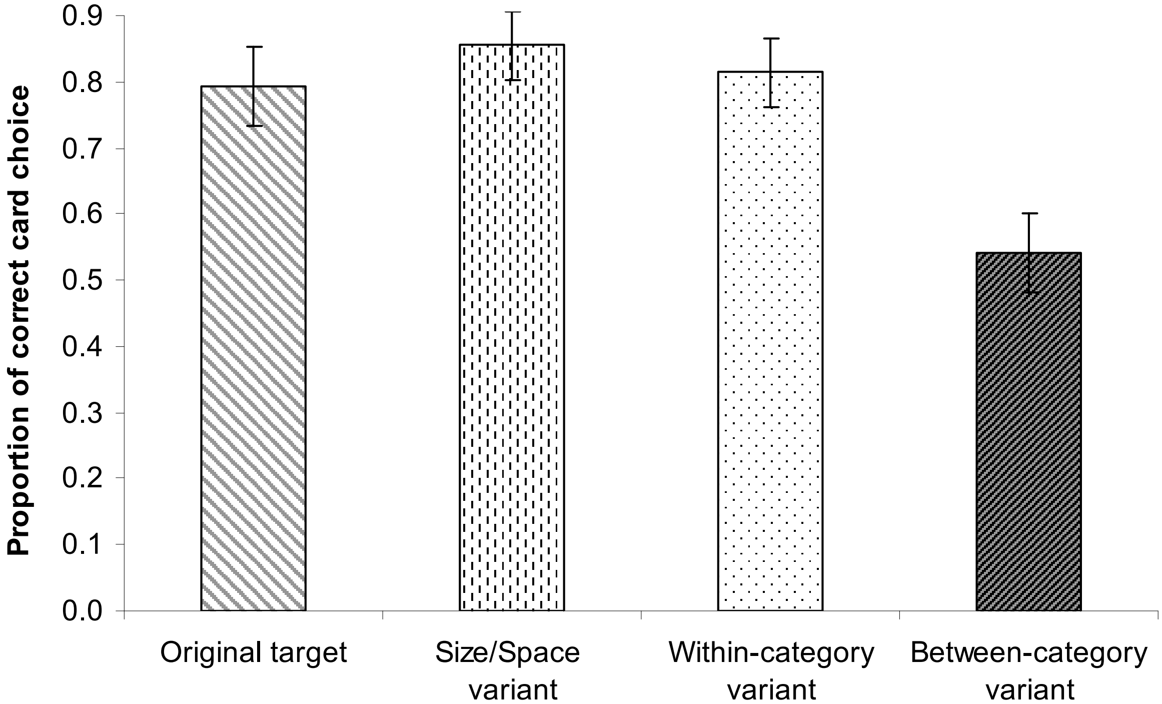
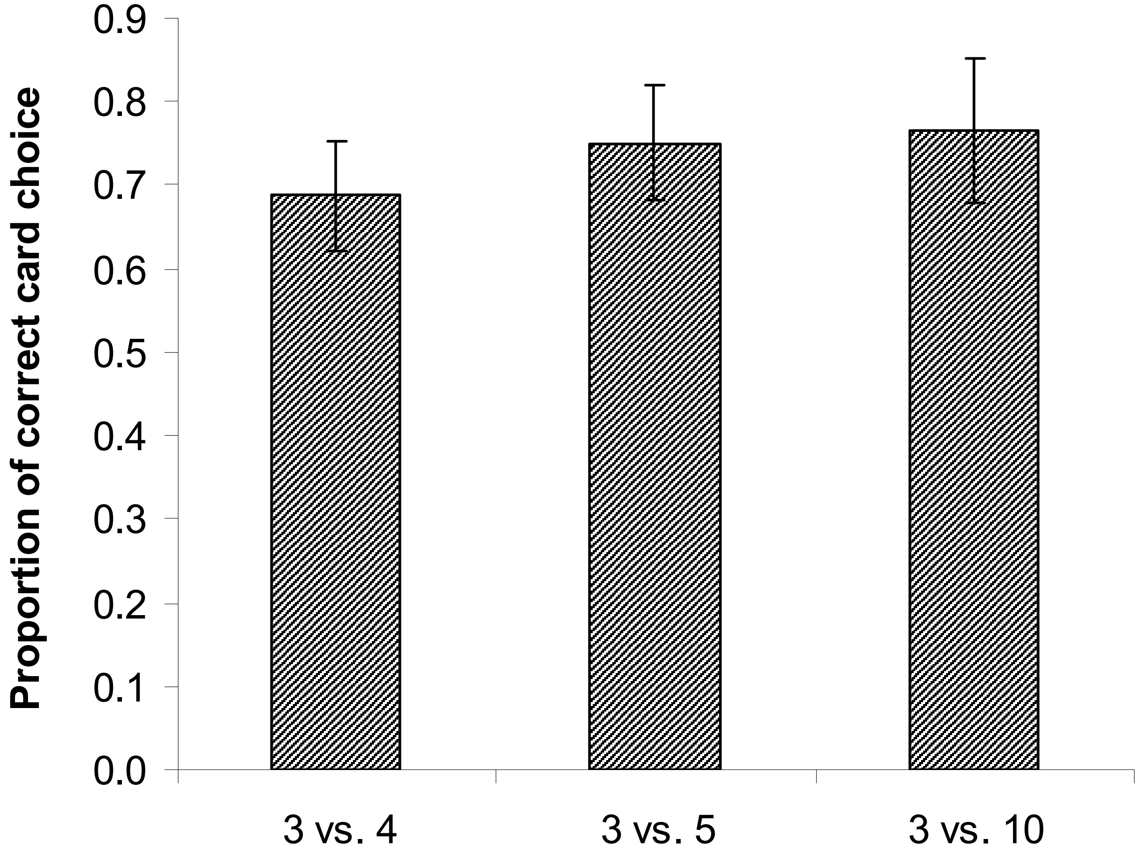

Proportion of correct card choice
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Original target
Size/Space variant
Within-category variant
Between-category variant

Figure 3


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Proportion of correct card choice
3 vs. 4
3 vs. 5
3 vs. 10