

Mutual Exclusivity Develops as a Consequence of Abstract Rather than
Particular Vocabulary Knowledge

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Abstract

Mutual exclusivity (ME) refers to the assumption that there are one-to-one relations between linguistic forms and their meanings. It is used as a word-learning strategy whereby children tend to map novel labels to unfamiliar rather than familiar referents. Previous research has indicated a relation between ME and vocabulary development, which could either be due to children's developing knowledge of the labels for familiar objects, or to enhanced general word-learning skills. In this study, we related ME to receptive vocabulary for 17-19-month-old children in a novel paradigm where we controlled for children's familiarity with the objects and labels. We found that only infants with larger receptive vocabularies employed ME. Our results indicate that ME use may not be available at the earliest stages of lexical acquisition, and, critically, that ME gradually consolidates as an abstract word-learning strategy as infants' linguistic experience increases.

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Infants and children rely on a number of default assumptions or strategies that allow them to successfully identify the referents of novel words in ambiguous or non-ostensive naming situations. Mutual exclusivity (ME) is one of these assumptions, which constrains novel labels to map onto unfamiliar rather than familiar referents (Markman & Wachtel, 1988). It is a robust finding that infants (e.g., Bion, Borovsky, & Fernald, 2013; Halberda, 2003; Markman, Wasow, & Hansen, 2003), children (Halberda, 2006), and adults (Halberda, 2006; Kalashnikova, Mattock, & Monaghan, 2014; Malone, Kalashnikova, & Davis, 2015) rely on this assumption when presented with labels with ambiguous meaning.

There is, however, debate over when ME emerges during the early stages of lexical acquisition, and the relation between ME use and infants' early lexical competence. The earliest manifestations of ME have been reported at 10-months of age (Mather & Plunkett, 2012; Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006), but other studies have not been successful in eliciting reliable ME responses in infants even at the age of 18 months (Bion et al., 2013; Mather & Plunkett, 2010). With respect to language development, there is also variation in the extent to which ME has been shown to relate to lexical development. Markman and colleagues provided evidence for early use of ME among 16- to 24-month-old infants (Liittschwager &

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Markman, 1996; Markman et al., 2003), at a point where vocabulary knowledge is limited. Markman et al. (2003), for instance, showed that infants with productive vocabularies below 50 words (so prior to the vocabulary explosion) were able to use ME, suggesting that it may be available at the onset of lexical acquisition as a constraint dedicated to facilitating the process of word learning (Markman, 1990; Markman & Wachtel, 1988; Merriman & Bowman, 1989), and therefore independent from lexical knowledge or experience.

However, there is converging evidence that infants' tendency to rely on ME in referent selection tasks *is* related to language development, as measured by vocabulary size (Graham, Poulin-Dubois, & Baker, 1998; Mervis & Bertrand, 1994). These studies showed individual differences among 16- to 22-month-old infants' performance in ME tasks whereby only infants with larger vocabularies demonstrated reliable use of the assumption. In a more recent study, Bion et al. (2013) assessed ME in 18-, 24-, and 30-month-old infants and showed that infants' ME use was significantly correlated with productive vocabulary scores in the older groups. However, in their study, for the 18-month-olds, no systematic use of ME was found and vocabulary size did not correlate to ME scores. Taken together, these findings show that it may not be the case that ME use is absent or present at a certain age, but that it emerges gradually as the infant's linguistic experience increases.

There are several possibilities for the way in which ME and vocabulary development are related. First, as reflected in a computational model of lexical acquisition (McMurray, Horst, & Samuelson, 2012), novel word recognition may benefit from experience with particular words that are familiar and that also appear in the word-learning situation. As the consolidated links between familiar labels and their referents become stronger, their links to novel referents are weakened leading to

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a stronger ME effect. This theoretical view of the relation between vocabulary and ME use is thus that infants' early lexical knowledge may have a direct influence on use of ME (Kucker, McMurray, & Samuelson, 2015; McMurray et al., 2012). That is, level of familiarity with the names of objects used as distracters in the ME task affects application of ME as a strategy.

A second alternative is that vocabulary development influences learning of the word-referent naming process. Thus, the increasing amount of exposure to one-to-one correspondences in linguistic input may also play a role in the emergence of ME as a word-learning strategy. Infants acquiring more than one language show a significantly weaker ME effect compared to their monolingual counterparts (Byers-Heinlein & Werker, 2009; Houston-Price, Caloghiris, & Raviglione, 2010), and the strength of their reliance on ME is related to the number of translation equivalents in their vocabularies (Byers-Heinlein & Werker, 2013). This indicates that ME use may be influenced by developing abstract knowledge of the relation between words and their referents.

A third alternative is that vocabulary size and ME are not directly related, but both have a separate independent cause. Such a view would be consistent with the domain-general perspective on ME, such that ME relates to general learning of the communicative process, which has consequences both for vocabulary knowledge and ME use (Baldwin & Moses, 2001). Furthermore, general attentional biases may account for infants' tendency to reason by exclusivity in fast-mapping tasks at the early stages of lexical development (Horst, Samuelson, Kucker, & McMurray, 2011; Hollich et al., 2000), and so ME may not be entirely consequential upon language learning. For instance, ten-month-old infants have been demonstrated to select novel objects as referents for novel labels as a function of a general bias towards

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attentionally-salient (Pruden et al., 2006) or novel objects (Mather & Plunkett, 2010). Similarly, Mather and Plunkett (2012) demonstrated that ME-like responses could be elicited based on a novelty bias even in situations when infants have not been presented with a competitor for which the label is familiar. In their experiments, 22-month-old infants were presented with a familiarised but not labelled novel object and a completely novel object (not familiarised). Upon hearing a novel label, infants selected the non-familiarised novel object (see Horst et al., 2011 for a similar finding with 24-month-old infants). Thus, honing these endogenous attentional biases may benefit early fast-mapping or referent selection processes (Houston-Price, Plunkett, & Duffy, 2006; Hollich et al., 2000).

In the most commonly used ME paradigm, distinguishing between these accounts of the role of vocabulary in ME has not been possible because particular vocabulary knowledge and general use of ME as a strategy are conflated. In the standard ME paradigm, infants are presented with two objects, one familiar (e.g., a spoon) and one unfamiliar (e.g., a whisk) and are requested to find the referent of a novel label (e.g., where is the *whisk*?). This paradigm requires that the child must first retrieve the meaning of the familiar label, identify the familiar object as its referent, and then exclude this object as a potential referent for the novel label. If the complexity of these processes increases due to low familiarity with that label, the child will be less likely to apply exclusion and avoid lexical overlap (Grassmann, Schulze, & Tomasello, 2015; Merriman & Marazita, 1995).

Grassmann and colleagues (2015) tested two, three, and four-year-old children's reliance on ME in a task where children's level of familiarity with the distracter labels was manipulated, such that children were either able to produce the familiar labels spontaneously, produce the labels upon request, or children were able to comprehend

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but not produce the labels. They showed that, above the contribution of age, label familiarity was a significant predictor of the extent to which children relied on the ME assumption: children were most likely to exhibit ME in cases where they were highly familiar with the label of the distracter object. Therefore, it is possible that the relation between children's size of the vocabulary and the emergence of the ME assumption is mediated by the level of familiarity with the objects and their labels used as distracters in the ME experimental paradigm. Using the standard ME paradigm (i.e., familiar distracter and an unfamiliar target in the presence of a novel label), it is thus not clear whether development of the ME assumption associated with vocabulary development is facilitated by particular knowledge of the specific words used as familiar labels in the study, or whether ME develops as an abstract assumption in tandem with vocabulary development. In this case, if familiarity is controlled, it may be the case that the use of ME will not be observed among young infants.

The present study investigated whether young infants were able to rely on ME, and whether the extent of their ME use would relate to individual vocabulary size in a fast-mapping situation that does not include familiar label competitors. We investigated ME use in a group of 17-19-month-old infants, at the age when vocabulary tends to begin to undergo significant growth (Nazzi & Bertoncini, 2003; Regier, 2003). A novel-novel ME preferential looking paradigm (Diesendruck & Markson, 2001) was employed where the infant's ability to use ME was assessed based on a recently established mapping. In contrast to the standard novel-familiar paradigms, infants were not presented with an object that was very familiar to them paired with a novel object. Instead, they were presented with two novel objects, one of which was previously named and the other was not, and were then asked to find a referent for a different novel label that they have not heard before. This paradigm

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enables us to control for the effects of familiarity of the competing label on young infants' ability to reason by exclusion in a fast-mapping task.

We first wanted to determine whether ME was observable in children prior to extensive language development, or whether it emerged gradually as vocabulary developed. The ME paradigm we used enabled us to extract the effect of individual vocabulary knowledge from observations of ME, which may have obscured previous studies' ability to detect ME prior to vocabulary development. Furthermore, we predicted that if ME depends on particular knowledge about individual words (Grassmann et al., 2015; McMurray et al., 2012) or general learning and attentional mechanisms (Horst et al., 2011; Mather & Plunkett, 2012), then the relation between vocabulary and ME should not be observed. If, however, ME develops as an abstract principle associated with vocabulary development in accordance with abstract knowledge about word-referent mappings, then infants should manifest reasoning by exclusion and increase their looks to the novel-unnamed object in response to the novel label in correspondence with their vocabulary size (Bion et al., 2013; Graham et al., 1998; Mervis & Bertrand, 1994).

Method

Participants

Twenty-seven 17- to 19-month-old infants (20 female) participated. Their ages ranged from 533 to 600 days ($M = 563.74$, $SD = 19.03$). Two additional infants participated but were excluded from final analyses because of equipment failure. All infants were typically developing and came from monolingual English-speaking families.

Infants' receptive vocabulary was assessed through the Oxford Communicative Development Inventory (CDI; Hamilton, Plunkett, & Schafer, 2000),

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an adaptation of the MacArthur-Bates CDI (Fenson et al., 1994) for use with infants raised in Britain. The mean receptive vocabulary score for the sample was 248.15 words ($SD = 97.09$).

Materials

Four three-dimensional object images (approximately 6 x 6 cm) were selected from the TarrLab Object Data Bank (1996). Two objects were familiar (familiarisation trial) and two were novel (test trials). The objects were embedded in a video sequence that also included the video and audio recording of a female speaker. This was a native English speaker who presented the stimuli in infant directed speech. The labels *banana*, *cup*, *toma*, and *modi* were used to refer to the familiar and unfamiliar objects, respectively. An audio recording of the speaker exclaiming, “Look! They are nice! Wow! They are pretty!” was recorded for the baseline phase. Each video sequence consisted of three phases: naming, baseline, and test (Figure 1).

[insert Figure 1 here]

Procedure

Naming phase. The speaker greeted the child by waving and saying, “Hello!”, then looked at the object and exclaimed, “Look!” Then, the speaker named the object three times while pointing at it and alternating gaze between the object and the child: “Look, it’s a *toma*. Oh, *toma*. Look, it’s a *toma*”.

Baseline phase. The objects moved to maintain the child’s attention, while an audio of the speaker’s voice played: “Look! They are nice! Wow! They are pretty!”

Test phase. First the image of the speaker appeared on the screen, no objects were visible. The speaker looked at the infant and made a request using a label different from the one used in the introduction phase, e.g., *modi*. Two carrier phrases were used for the requests throughout the experiment: “Where is the [label]?” and

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“Find the [label]!”), to maintain interest throughout the multiple trials. Then, the image of the speaker disappeared, and the two objects were presented side by side on the screen accompanied by a voice recording of the label, e.g., *Modi!* This final frame of the video was frozen on the screen for 4 seconds. Then, the target object rotated and the two objects disappeared. This technique is commonly used in infant preferential looking paradigms to maintain attention, as it does not create reinforcement for the infants’ responses (Halberda, 2003).

All participants saw one familiarisation trial where familiar objects were used followed by three test trials. The same object pairing was used for each test trial. Here, the two objects were unfamiliar and novel labels were used to name and request the objects. Data was collected using a Tobii X750 eye tracking system. Stimuli were presented through Tobii Clearview software on a 32in TV monitor. The infant sat on their caregiver’s lap in a quiet room free from distraction, approximately 60 cm away from the monitor. Caregivers were instructed to look away from the screen. The experimenter controlled the study from a computer located out of sight of the infant. Prior to the study, a five-point infant calibration routine was used.

The two phases of interest for the analyses were baseline and test. Each phase included two areas of interest: the distracter object and the target object. The side of presentation of the target object (right and left side of the screen) was alternated across trials. Fixation duration at each object was recorded at 250 ms after the onset of the test label for 2000 ms following previous research using preferential looking paradigms (e.g., Swingley & Aslin, 2000; Swingley & Fernald, 2002) since fixations after the 2000 ms cut-off point cannot be reliably interpreted as a response to the auditory stimulus. These measures were converted into proportions of time that the infant spent fixating at each object out of the two possible objects (distracter or

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target), and then averaged across the three test trials. Fixations at target in the test phase were compared to fixations at target in the baseline phase to ensure that an increase in fixation compared to the distracter occurred in response to the target label as opposed to a visual preference for the target.

Results

In order to assess whether infants attended to the target object as a function of the target label, fixation durations at the target in baseline and test phases was compared in the familiarisation and novel label trials. In the familiarisation trial, infants directed a significantly higher proportion of looks to the target object in the test compared to the baseline phase, $t(26) = 3.081, p = .005, d = 1.208$. That is, infants were engaging with the task and were capable of attending to the request from the speaker.

Then, infants' performance in the test trials was assessed. Infants' vocabulary scores were included to account for the effect of individual linguistic proficiency. A repeated measures ANCOVA with phase (baseline, test) as factor and CDI receptive vocabulary score as covariate showed a significant effect of phase indicating an overall ME effect, $F(1, 23) = 6.749, p = .016, \eta^2 = .227$, no main effect of CDI, $F(1, 23) = 2.239, p = .148, \eta^2 = .089$, but, critically, a significant phase by CDI interaction, $F(1, 23) = 9.772, p = .005, \eta^2 = .298$. Infants significantly increased their looks at the target object in response to the novel label, in proportion to their receptive vocabulary size.

To investigate individual differences in ME use, a ME score was calculated for each infant as the difference between the proportion of looks directed to the target in test compared to the baseline condition where a larger difference score denoted a larger proportion of looks directed at target in response to the novel label. A partial

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correlation analysis controlling for infants' age showed a significant relation between infants' ME difference scores and their receptive vocabulary size, $r(22) = .540$, $p = .006$. To further test this relation, a larger vocabulary ($n = 14$; *Mean* CDI = 322.57, *SD* = 65.86) and a smaller vocabulary ($n = 13$; *Mean* CDI = 168, *SD* = 48.02) subgroup were created based on the median split of vocabulary size scores (*Median* = 225). An independent-samples *t*-test with ME difference scores as the dependent variable demonstrated that indeed infants with larger vocabulary size showed significantly greater ME use than infants with smaller vocabulary size, $t(23) = -2.140$, $p = .043$, $d = .89$ (Figure 2).

[insert Figure 2 here]

Discussion

The present study revealed that ME use by 17- to 19-month-old infants was related to their receptive vocabulary size, even when knowledge of the labels within the task was controlled. Infants with larger vocabularies were more consistent in directing their looks to an unfamiliar than a familiar object in response to a novel label. These results align with the view that ME is a gradually developing strategy in relation to infants' vocabulary proficiency and individual linguistic experience.

Our findings, therefore, fail to confirm that ME operates as an assumption that facilitates fast-mappings at the early stages of language acquisition (Markman et al., 2003). A closer inspection of our data shows that infants in the smaller vocabulary group who were not employing ME had a receptive vocabulary score of approximately 160 words, which can correspond to over 200 words in their vocabulary (Mayor & Plunkett, 2011). Thus, infants who did not reliably use ME in our experiment did seem to be capable of acquiring this number of words successfully, consistent with the view that ME is not likely to be a necessary

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precursor of early vocabulary acquisition. Instead, our findings indicate that ME use becomes reliable when infants have acquired more extensive lexical competence.

Previous studies that have demonstrated a relationship between children's early ME use and their vocabulary size have used highly familiar distracters (e.g., Bion et al., 2013; Graham et al., 1998; Houston-Price et al., 2010), which meant that children's tendency to reason by exclusion may have been mediated by their level of familiarity with the distracter and its label (Grassmann et al., 2015). However, the use of two unfamiliar objects in this task demonstrates that this relationship is significant even when children's familiarity with the distracter and its label are controlled for. Exposure to objects (Fennell, 2012; Kucker & Samuelson, 2012) and labels (Swingley, 2007) used in the paradigm can facilitate encoding of novel labels in experimental tasks. Especially in the case of ME, higher familiarity with the distracter's label can lead to higher reliance on ME due to increased competition between the labels in the vocabulary and consequently a decrease in the complexity of the task (Grassmann et al., 2015). Here we demonstrate that, in addition, higher linguistic competence manifested in larger vocabulary size also facilitates performance in this referent selection task.

In order to control for children's familiarity with the object and label used as distracters, our paradigm required infants to establish an initial novel object-novel label mapping before proceeding to the disambiguation task. That is, infants were required to first encode the distracter object-label mapping presented in the naming phase to identify the referent of the novel label via ME reasoning. Thus, it could be the case that infants' overall ability to map novel labels to novel objects was also mediating their performance in this task. It is well known that infants at 18 months are successful at establishing word-object associations after a limited exposure time in

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computerised tasks (e.g., Bion et al., 2013; Byers-Heinlein, Fennell, & Werker, 2013; Stager & Werker, 1997; Yoshida, Fennell, Swingley, & Werker, 2009), but it is still possible that some infants were more successful at establishing and retaining these initial mappings than others. Therefore, good word learners overall may have also been good at using ME. This possibility, however, is not contradictory to our conclusions. If ME emerges as a product of more extensive word-learning experience, it is natural for it to be related to infants' general fast-mapping and familiar word processing skills (McMurray et al., 2012).

The present study does not allow us to exclude the possibility that infants were relying on more general non-linguistic or pragmatic information to disambiguate the meaning of the novel labels in this task (Horst et al., 2011; Mather & Plunkett, 2012; Pruden et al., 2006). Even though an effort was made to equate the salience of the two novel objects, infants did receive more exposure to the distracter than to the target object (i.e., infants saw the distracter in the naming, baseline, and test phases, but they saw the target only in the baseline and test phases). In addition, unlike the commonly used preferential looking ME paradigm (e.g., Bion et al., 2012; Byers-Heinlein & Werker, 2009; Halberda, 2003; Houston-Price et al., 2010), the present task included a speaker who provided referential cues in the naming phase (i.e., gaze and pointing), which could have been more effective at capturing young infants' attention to information presented in that phase, and could have been interpreted as an intention to single out the distracter object. Gesture use by pre-linguistic children and their caregivers can, for instance, predict later vocabulary development (Rowe & Goldin-Meadow, 2009). Therefore, it is possible that infants were mapping the unfamiliar label to the most novel object presented in the task. However, this interpretation cannot entirely account for our findings. First, the present analyses compared infants'

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fixation duration at target in the baseline and test phases, ensuring that an increase in fixation duration at test would indicate a response to the novel label above any pre-existing individual preferences for the object. Second, the novelty account does not explain the significant effect of vocabulary size found in this study since this type of attentional bias can guide fast-mapping behaviours even before infants' first birthday when their vocabulary size is very limited (Pruden et al., 2006). Therefore, our findings suggest that 17- to 19-month-old infants in this study were using ME as an abstract word-learning strategy instead, which use was shaped by their own lexical experience.

Our results add to the growing evidence for a developmental and a dynamic view of ME rather than postulating it as a lexical constraint that becomes available at a certain point in development. While very young infants may be able to resolve exclusivity-based problems by relying on endogenous learning and attentional biases, as they grow older, they recruit other sources of information such as their individual linguistic experience and understanding of the linguistic and non-linguistic input to solve the task of fast-mapping (Hollich et al., 2000). This also emphasises the influence of the experimental paradigm and stimuli on infants' ability to reliably use ME: factors such as saliency and referential cues (Hollich et al., 2000), familiarity of the competing label (Grassmann et al., 2015), phonological form of the novel label (Mather & Plunkett, 2011; Merriman & Schuster, 1991), similarity of the novel exemplar to other familiar objects (Merriman & Marazita, 1995), and number of familiar competitors (Horst, Scott, & Pollard, 2010) can all affect whether the assumption is manifested or not at a certain age.

It is well known that young infants and children reason by exclusivity to identify the referents of novel labels presented in non-ostensive communicative

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situations. From early on, infants can manifest this reasoning by relying on a number of endogenous attentional biases that guide them to map unfamiliar labels to the more novel or salient objects in their environment. This mapping process is also aided by lexical competition, which arises when the child is highly familiar with the distracter or distracters presented in the task. However, this study demonstrates that general learning mechanisms and familiarity with competing labels cannot account for all the early manifestations of ME. Here, infants who were more experienced language users were capable of employing ME even in a more complex situation where referent selection relied on a recently established mapping and thus competition between two novel labels and novel objects. Therefore, with increasing linguistic experience and maturation of social and communicative skills, basic learning mechanisms can be transformed into more sophisticated strategies such as ME. This can lead to a more systematic use of this strategy, which is interlinked with infants' emerging communicative skills and increasing vocabulary knowledge.

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EARLY USE OF MUTUAL EXCLUSIVITY

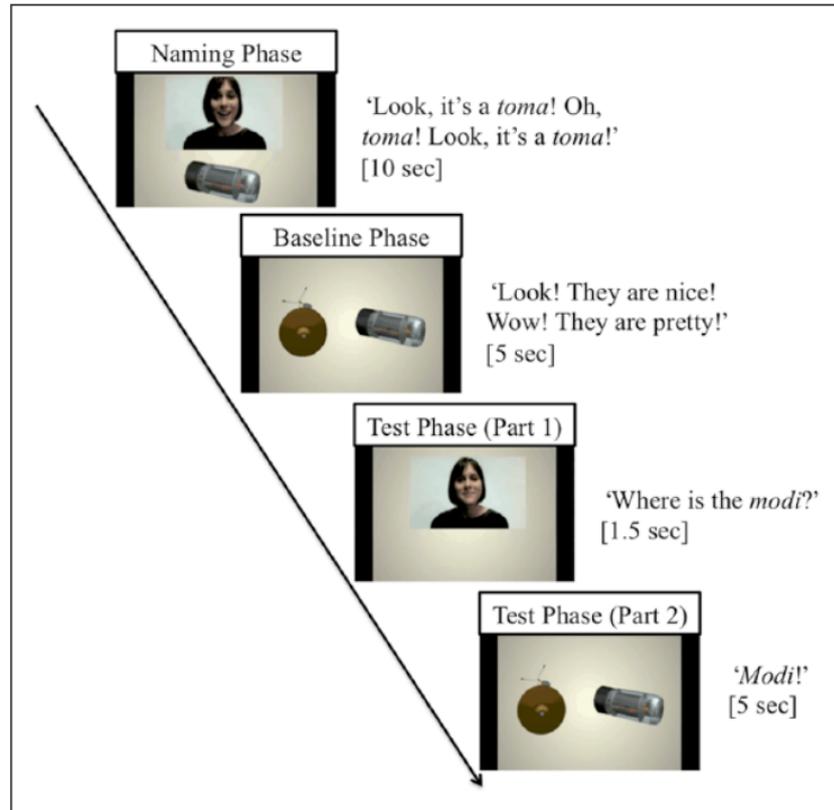


Figure 1. Graphical representation of the ME task.

EARLY USE OF MUTUAL EXCLUSIVITY

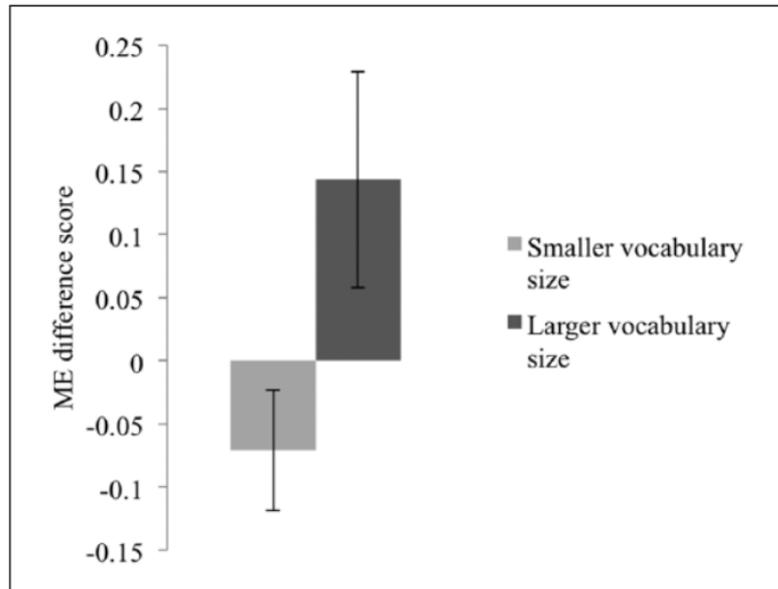


Figure 2. ME difference scores for the smaller ($n = 13$) and larger vocabulary ($n = 14$) sub-groups (error bars represent standard error of the means).

EARLY USE OF MUTUAL EXCLUSIVITY

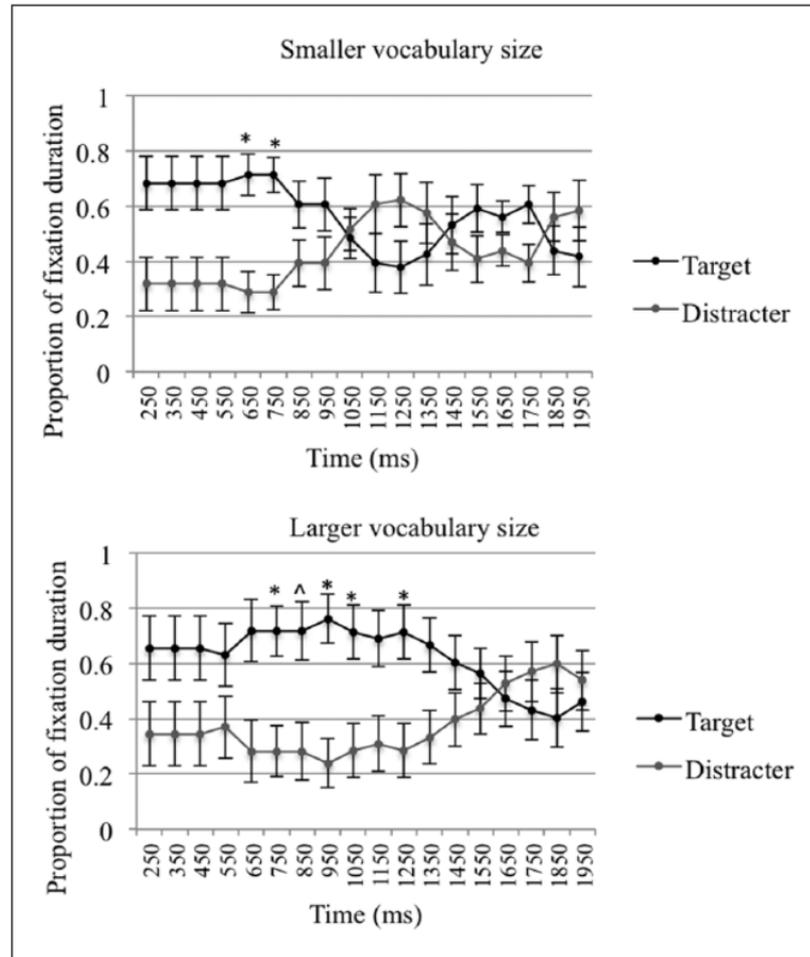


Figure 3. Time course fixation patterns to the target and distracter objects by the smaller ($n = 13$) and larger ($n = 14$) vocabulary sub-groups (one-sample t -test analyses against chance performance; chance = .05; * $p < .05$; ^ $p = .062$). Error bars represent standard error of the means.