Remembering when Words are Mutually Exclusive

Emily Mather (emily.mather@psy.ox.ac.uk)
Department of Experimental Psychology, University of Oxford
South Parks Road, Oxford, UK. OX1 3UD.

Kim Plunkett (kim.plunkett@psy.ox.ac.uk)
Department of Experimental Psychology, University of Oxford
South Parks Road, Oxford, UK. OX1 3UD.

Abstract
During the second year of life, infants develop a ‘mutual exclusivity’ bias to attach novel object labels to novel, name-unknown objects, rather than familiar, name-known objects (Markman, 1989). In an intermodal preferential looking experiment with 19.5- and 22.5-month-old infants, stimulus repetition was critical for observing mutual exclusivity. On the first occasion that a novel label was presented with a familiar and novel object, looking behaviour was unsystematic. Upon re-exposure to the same stimuli, 22.5-month-olds looked preferentially at the novel object prior to the re-presentation of the novel label. These findings suggest a powerful memory mechanism for novel labels and objects, enabling mutual exclusivity to emerge across repeated exposures to potential referents.

Keywords: Infancy; word learning; cognitive development; language acquisition; psychology.

Introduction
Early word learning is a multi-faceted task where infants draw upon multiple sources of information to disambiguate the meaning of new words (Hirsh-Pasek, Golinkoff, & Hollich, 2000). In some instances, disambiguation may arise from cognitive biases that the infant brings to the structure of the word-learning environment. This form of disambiguation is exemplified by ‘mutual exclusivity’ – a response bias that is argued to lead infants to ignore second names for name-known objects (Markman, 1989, 1990). If an infant hears a novel label in the presence of both a familiar, name-known and novel, name-unknown object, then mutual exclusivity will result in the infant selecting by default the novel object as the referent of the novel label.

Investigations of mutual exclusivity (or related principles) reveal a considerable discrepancy in the age at which infants first use this word-learning heuristic. Studies by Merriman and colleagues (Merriman & Bowman, 1989; Merriman & Schuster, 1991; Merriman & Stevenson, 1997) suggest that infants use a rudimentary form of mutual exclusivity from around two years of age. However, more recent investigations by Halberda (2003) and Markman, Wasow, and Hansen (2003) suggest that infants use mutual exclusivity from around 15 to 17 months of age.

There are a number of possible reasons why experiments differ in the age at which mutual exclusivity is observed. One possible source of variation is the response format. Studies by Merriman and colleagues require infants to execute an overt response (e.g., reaching or pointing), whereas Halberda uses looking time as an index of comprehension. A further difference is that studies by Merriman and colleagues use a ‘forced-choice’ response, whereas the looking time measure used by Halberda allows for a continuous distribution of attention across potential referents (c.f. Samuelson, Horst, Dobbertin, & Schutte, 2006). Another source of variation across studies is stimulus processing load. As one example, Experiment 1 of Merriman and Bowman presents toddlers with a larger set of novel stimuli than in Halberda (2003) and Markman et al. (2003). This type of variation may be one reason why Halberda (2003) and Markman et al. (2003) found evidence for mutual exclusivity at 15 to 17 months of age, while Merriman and Bowman only found evidence at 3 years of age.

To explore systematically the effect of processing load on the use of mutual exclusivity, Evey and Merriman (1998) presented 25-month-olds with novel labelling trials consisting of one novel object and either one or three familiar objects. Infants were significantly more likely to select the novel object as the referent of the novel label in the smaller stimulus sets compared to the larger sets. Evey and Merriman (1998) concluded that the presence of multiple familiar objects increases processing load because the infant has a greater number of familiar labels to retrieve before they can produce a mutually exclusive response.

The aim of the present experiment is to explore whether manipulating the number of stimulus presentations will facilitate the mutual exclusivity response. Within the adult memory literature, the facilitated processing of specific items as a result of previous exposure to those items is referred to as repetition priming (Gupta & Cohen, 2002). While there is debate over the specific form of memory responsible for repetition priming (McClelland, McNaughton, & O’Reilly, 1995; Kirsner & Speelman, 1996), retention of information across stimulus exposures is required to alter performance. Therefore, the present study will manipulate stimulus exposure in the form of trial repetition to determine whether or not infants’ use of mutual exclusivity is enhanced by prior stimulus exposures. Infants will be aged 19.5 and 22.5 months, and therefore between the ages at which different studies find evidence of mutual exclusivity.

The present study uses a Intermodal Preferential Looking (IPL) task (Golinkoff, Hirsh-Pasek, Cauley, &
Gordon, 1987) to deliver controlled stimulus presentations. Infants are presented with a series of trials with images of one familiar and one novel object and an auditory stimulus. Each trial was accompanied by either the name for the familiar object, a novel name for the novel object, or a neutral linguistic stimulus. The experiment can provide robust evidence of mutual exclusivity, through a comparison between trials presenting a novel label and trials presenting a neutral phrase. The other significant variable is the repetition of each trial during the experiment. If infants retain information from one stimulus exposure to the next, then their attention to the correct referent of a label (i.e., attention to the novel object upon hearing a novel label) may be enhanced on the repeat presentation of a trial.

Method

Participants
Thirty-five full-term infants at 19.5 months of age (M = 19.5 months, Range = 19.3-19.8 months; 19 male and 16 female) and 32 full-term infants at 22.5 months of age (M = 22.5 months, Range = 22.2-23.0 months; 19 male and 13 female) participated in the experiment. Eight additional 19.5-month-olds were tested but excluded due to fussiness (6) or experimenter error (2). Eleven additional 22.5-month-olds were tested but excluded due to fussiness (8), parental interference (1), or experimenter error (2). All infants had no known hearing or visual problems and were recruited via the maternity ward at the local hospital. All but two infants came from homes where British English was the only language in use; two 22.5-month-olds came from homes where a minority second language was spoken. Prior to participation, all parents were asked to complete a British adaptation of the MacArthur-Bates Communicative Development Inventory (CDI) (Hamilton, Plunkett, & Schafer, 2000).

Stimuli
Auditory Stimuli Speech stimuli were produced by a female speaker of British English in an infant-directed manner. The stimuli were digitised at a sampling rate of 44.1 kHz in stereo with a sample size of 16 bits. The stimuli were edited to remove background noise and match average volume. The stimuli were 12 familiar object labels (ball, book, car, chair, clock, cup, hat, key, shoe, sock, spoon, train) and four novel object labels (blick, gop, meb, wag) each uttered in the frame “Look at the [X]!” and the control phrase “Look at that!”.

Visual stimuli Object images were JPG files in 24 bit colour with a display size of 32 x 24 cm and a resolution of 300 x 300 pixels (files were horizontally compressed from 400 to 300 pixels to accommodate to a widescreen display). Twelve name-known images were of typical exemplars corresponding to the 12 familiar object labels, and 12 name-unknown images were of unusual objects that the infants were unlikely to have seen or hear named (e.g., compass, hair curler, etc.). All object images were set against a pale grey background and differed in colour. Examples are provided in Figure 1. An 8 cm square image of a red cross was used as an orienting stimulus.

Design
The experiment consisted of 24 trials, each presenting a familiar and novel object. Each trial lasted 6 s, accompanied by one of three types of auditory stimulus: Familiar Label trials, presenting the name for the familiar object, Novel Label trials, presenting a novel label for the novel object, and Control trials, presenting the phrase “Look at that!”.

The onset of all familiar and novel labels (or ‘that’ for control trials) was at 2633 ms into the trial. Allowing for a latency of 367 ms to process the label (Swingley & Aslin, 2000), trials were split into equal 3 s pre- and post-naming phases.

The 24 trials were split into two halves of 12 trials; a different set of object and labels was presented in each half. Each half was further divided into two blocks of six trials. The first block of trials in each half presented two examples of each trial type: Two Familiar Label trials, two Novel Label trials, and two Control trials (see Figure 1). The second block of trials in each half presented the same sequence of trials as the first block, counterbalancing for side of presentation. Therefore, for a given trial there was an Original presentation in the first block, and a Repeat presentation in the second block. Because the second block presented trials in the same order as the first block, there was always a distance of six trials between the original and repeat presentations of a trial.

To create the pairs of objects for the experiment, two sets of 12 familiar and novel object pairs were randomly constructed, with the constraint that no pair was repeated between sets. Approximately half the infants were tested on one set, while the remaining infants were tested on the other set. Each pair of objects served under all three trial type

<table>
<thead>
<tr>
<th>Trial type</th>
<th>Object pair</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novel</td>
<td>![Image](391x227 to 415x246)</td>
<td>“Look at the blick”</td>
</tr>
<tr>
<td>Control</td>
<td>![Image](391x248 to 416x267)</td>
<td>“Look at that!”</td>
</tr>
<tr>
<td>Familiar</td>
<td>![Image](391x184 to 416x203)</td>
<td>“Look at the hat”</td>
</tr>
<tr>
<td>Novel</td>
<td>![Image](391x269 to 417x289)</td>
<td>“Look at the gop”</td>
</tr>
<tr>
<td>Familiar</td>
<td>![Image](392x164 to 413x182)</td>
<td>“Look at the spoon”</td>
</tr>
<tr>
<td>Control</td>
<td>![Image](427x248 to 452x266)</td>
<td>“Look at that!”</td>
</tr>
</tbody>
</table>

Figure 1: Example of a trial block
conditions; thus, whether a given object pair was accompanied by a familiar label, a novel label, or the control phrase was counterbalanced across infants. The pairing of novel labels with object pairs was partially counterbalanced across infants such that each novel label was rotated across six object pairs. Within each trial block, familiar and novel objects appeared an equal number of times to the left- and right-hand side of the display. Side of presentation was counterbalanced for every trial type within a block, and for every object pair between Original and Repeat presentations of a trial.

**Procedure**

Infants sat on their caregiver’s lap facing a flat widescreen display with their eyes at a distance of approximately 0.8 m, and level with the vertical midpoint of the images. Images were positioned on screen at distance of 62 cm centre-to-centre, with the infant positioned at an equal horizontal distance from both images. Two cameras mounted directly above the horizontal midpoints of each image recorded infants’ eye movements. Auditory stimuli were delivered via two loudspeakers centrally positioned side-by-side above the display. Caregivers were asked to keep their eyes closed, to wear headphones (playing music to mask the auditory stimuli), and to not point at the screen. Trials were manually launched by the experimenter when the infant was looking towards the screen. If the infant was looking away between trials, the auditory and/or visual orienting stimuli were presented to return the infant’s gaze to centre.

**Results**

**Scoring** A digital video offline scoring system was used to assess infants’ eye movements on a frame-by-frame basis (every 40 ms) by a skilled blind coder. This technique enabled tracking of every saccade, coded either as left looking, right looking or other looking.

**CDI analysis** All but one of the familiar labels were reported as comprehended by > 88% of 19.5-month-olds and > 90% of 22.5-month-olds. The only label to fall short of this level was ‘clock’ (80% at 19.5 months and 88% at 22.5 months). Houston-Price, Mather, and Sakkalou (2007) have observed that British parents underestimate comprehension vocabulary for infants in the second year of life. Therefore, actual comprehension levels for each word may exceed those reported. Nineteen-and-a-half-month-olds were reported to have a mean comprehension vocabulary of 254 words ($SD = 83$) and a mean production vocabulary of 77 words ($SD = 62$); 22.5-month-olds were reported to have a mean comprehension vocabulary of 326 words ($SD = 78$) and a mean production vocabulary of 222 words ($SD = 110$). Comprehension ($t(65) = -3.68, p < .001, d = .90$) and production ($t(50.1) = -6.99, p < .001$; Greenhouse-Geisser corrected) vocabulary sizes were significantly larger at 22.5 months than 19.5 months.

**Preliminary Analysis** A proportional measure was calculated (by dividing total looking time to the familiar object by total looking time to both object) for the pre- and post-naming phases of every trial. These proportions were averaged across the two examples of each trial type for each block of six trials. Unexpectedly, comparisons to chance revealed significant effects during the pre-naming phases of Repeat trials. Thus, 19.5-month-olds had a significant preference for the familiar object during the pre-naming phase of Familial Label trials, while 22.5-month-olds had both a significant preference for the familiar object during the pre-naming phase of Familial Label trials and a significant preference for the novel object during the pre-naming phase of Novel Label trials. Therefore, a more extensive analysis of within-trial looking behaviour was undertaken to interpret this pattern of effects.

**Main Analysis** Each trial was split into four equal 1.5 s trial phases; thus, there were two pre-naming phases (0–1.5 s and 1.5–3 s) and two post-naming phases (3–4.5 s and 4.5–6 s). Initial analyses revealed that the factors of experiment half and sex did not interact with trial type; hence the analysis is collapsed across these factors. A mixed-model ANOVA with the factors of trial repetition, trial type, trial phase, and age revealed significant main effects of trial type ($F(1,82, 130) = 10.5, p < .001$; Greenhouse-Geisser corrected) and trial phase ($F(3, 195) = 5.54, p = .001$), significant interactions between trial type and trial phase ($F(5,15, 390) = 5.02, p < .001$; Greenhouse-Geisser corrected), trial repetition, trial type and trial phase ($F(6, 390) = 2.59, p < .025$), and a marginal interaction between trial repetition, trial type, trial phase, and age ($F(6, 390) = 1.86, p = .086$).

To interpret this set of interactions, the effects of trial repetition, trial type, and trial phase were analysed separately for each age group. At 19.5 months of age, although there were significant effects of trial type ($F(2, 68) = 4.51, p < .025$), trial phase ($F(3, 102) = 3.31, p < .025$), and an interaction between trial type and trial phase ($F(4.4, 148.7) = 2.95, p < .025$), there was no significant interaction between trial type, trial phase, and trial repetition. In contrast at 22.5 months of age, there were significant effects of trial type ($F(2, 62) = 6.30, p < .005$), trial phase ($F(3, 93) = 3.24, p < .05$), and significant interactions between trial type and trial phase ($F(6, 186) = 2.93, p < .01$), and trial type, trial phase, and trial repetition ($F(6, 186) = 3.72, p < .005$).

Figures 2 to 5 illustrate the effects of trial type, trial phase, and trial repetition on infants’ attention to the familiar object (for Figures 2 to 5, * $p < .05$, ** $p < .005$, two-tailed). At 19.5 months, there is a similar pattern of effects across Original and Repeat trial presentations. During Original trials (see Figure 2), there is a significant preference for the familiar object on Familial Label trials during the trial phase immediately following naming ($M = 63.9\%, SD = 15.1, t(34) = 5.46, p < .001$). During Repeat trials (see Figure 3), 19.5-month-olds have a significant preference to attend to the familiar object in the Familial Label condition both before (1.5–3 s trial phase: $M = 59.5\%, SD = 18.5, t(34) = 3.03, p = .005$) and after (3–4.5 s trial
phase: $M = 63.2\%$, $SD = 21.4$, $t(34) = 3.65$, $p = .001$; 4.5–6s trial phase: $M = 63.6\%$, $SD = 20.1$, $t(34) = 3.98$, $p < .001$)

the onset of naming. However, there are no significant preferences for the novel object in the Novel Label condition, for either Original and Repeat trials.

At 22.5 months there is an effect of trial repetition on how attention to the familiar object unfolds over time within each condition. During Original trials (see Figure 4), there is a significant preference for the familiar object in the Familiar Label condition following the onset of naming. There are no other significant effects. A very different pattern of effects occurs during Repeat trials, as can be observed in Figure 5. For Repeat trials, significant effects occur in the Familiar Label and Novel Label conditions prior to the onset of naming. Specifically, during the 1.5–3s trial phase, there is a significant preference to attend to the familiar object in the Familiar Label condition ($M = 64.3\%$, $SD = 19.6$; $t(31) = 4.13$, $p < .001$), yet a significant preference to attend to the novel object in the Novel Label condition ($M = 42.7\%$, $SD = 16.1$; $t(31) = -2.57$, $p = .015$). There is also a preference for the familiar object in the Control condition during the 1.5–3s trial phase ($M = 56.2\%$, $SD = 14.1$; $t(31) = 2.50$, $p < .025$).

The preference to attend to the familiar object in the Familiar Label condition is sustained during the 3–4.5s trial phase ($M = 61.9\%$, $SD = 22.1$, $t(31) = 3.05$, $p = .005$), as is the preference to attend to the novel object in the Novel Label condition ($M = 42.2\%$, $SD = 17.7$, $t(31) = -2.49$, $p = .018$).

Finally, the Control condition was included to determine whether the effects observed in the Novel Label condition are specific to the presentation of a novel label, rather than a more general effect caused by the presentation of a directive phrase or the absence of a familiar label. For Repeat trials at 22.5 months, there is a significant difference between the Novel Label and Control conditions for the 1.5–3s (56.2% vs. 42.7%; $t(31) = -3.62$, $p = .001$), and 3–4.5s (54.9% vs. 42.2%; $t(31) = -2.39$, $p < .025$) trial phases. Thus, the significant preference 22.5-month-olds display for the novel object during repeat presentations of Novel Label trials appears to be specific to the presentation of a novel label.²

² The exclusion of trials where the familiar object was not reported as name-known resulted in a similar set of findings. There were no significant effects of a median split on comprehension vocabulary size for analyses within each age group.

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¹ A similar pattern of findings was obtained with the exclusion of the two 22.5-month-olds from homes with a second minority language.
**Discussion**

The aim of this experiment was to explore the effect of manipulating stimulus exposure on the mutual exclusivity response. Trials presenting pairs of familiar and novel objects with either a familiar label, a novel label, or a neutral control phrase were presented twice during a brief IPL experiment to explore the impact of trial repetition. As hypothesized, trial repetition was an important factor in observing the use of mutual exclusivity. At 22.5 months of age, a significant preference to attend to the novel object in the Novel Label condition was observed only for Repeat trial presentations. At 19.5 months of age, no preference for the novel object was found for either Original or Repeat presentations of Novel Label trials.

Importantly, 22.5-month-old infants’ behaviour on Novel Label trials differs to their behaviour on Control trials, providing strong evidence that their looking preferences are specific to hearing a novel label, and thus an outcome of mutual exclusivity. The mutual exclusivity response is also clearly facilitated by stimulus repetition. At 22.5 months, information retained from original stimulus presentations supports the completion of the mutual exclusivity response upon the re-presentation of the stimuli. As discussed below, 22.5-month-olds appear to remember that a novel label was presented with a specific pair of objects, indicating a robust memory for novel labels undisrupted by the intervening presentation of a variety of objects and labels.

The failure of 19.5-month-old infants to use mutual exclusivity in this experiment contrasts with the finding of Halberda (2003) who found that younger, 17-month-old infants would respond in a mutually exclusive manner in an IPL task. The discrepancy between the two studies must be attributed to procedural differences. Although trials were repeated in the present study, infants were nonetheless presented with a greater number of novel stimuli than in Halberda. Furthermore, in Halberda (2003) the object pair accompanied by a novel label was on other occasions accompanied by the name for the familiar object. In the present study, the familiar object on Novel Label trials was never labelled on a separate trial. Thus, the labelling of familiar objects may also be important.

Consequently, the age at which an infant can use mutual exclusivity appears be influenced by the particular processing demands of a labelling event. While infants younger than 19.5 months appear able to use mutual exclusivity in some circumstances, in the present study only 22.5-month-olds displayed evidence of mutual exclusivity. Furthermore, 22.5-month-olds use of mutual exclusivity depended on stimulus repetition. The use of mutual exclusivity to acquire novel word mappings from brief, incidental exposures may require multiple or extended encounters with these situations to enable adequate stimulus processing.

The present study also differs to Halberda (2003) in how the mutual exclusivity response manifests itself in looking behaviour. In Halberda’s study, 17-month-olds’ displayed a significant increase in attention to a novel object between the pre- and post-naming phases of a trial. In the present experiment, evidence of a mutual exclusivity response did not immediately follow hearing a novel label; rather it occurred only after the repeat presentation of the familiar and novel objects. Because the effect on Repeat trials occurs before the re-presentation of the novel label, one might argue that a general bias to attend to the novel object, as an outcome of habituation, could drive the pre-naming preference for the novel object. However, the direction of pre-naming preferences during Repeat trials is contingent upon the trial type. Because there is a significant difference between the novel label and control labelling conditions on Repeat trials, it is unlikely that the effect is an outcome of a general habituation process; rather the effect is specific to the presentation of a novel label during the Original trials. Therefore, the 22.5-month-olds provide evidence of applying mutual exclusivity.

For the infants to be capable of displaying the pattern of behaviour observed at 22.5 months, they have to: i) process and retain information from the Original trials, ii) retrieve this information during Repeat trials, and iii) use this information to direct their attention during Repeat trials. However, there are a variety of different cognitive processes that could support this sequence of events. One possibility is that only information about the objects is retained between Original and Repeat trials, with familiar and novel labels ‘highlighting’ the familiar and novel objects respectively. For repetitions of Familiar Label trials the infants might continue to attend to the object they were previously looking at during the original Familiar Label trials. Thus, the infant may not remember the label per se, but engage in perseverative looking to the object labelled on the original trial. Similarly, on original Novel Label trials, the novel label could have altered infants’ interest or memory for the novel object, even in the absence of a significant preference for the object. Hence, for repetitions of Novel Label trials, infants’ interest in the novel object could be caused by the enhanced salience of the novel object.

Two further explanations require the 22.5-month-olds to retrieve a memory of the novel label during the pre-naming phase of the repeat Novel Label trials. Possibly, the infant has remembered that all three stimuli (label and objects) occurred together during the original presentation of a trial, without specifically associating the novel label with the novel object. In other words, the 22.5-month-olds could have formed either an episodic memory of the Original trial (see Richards & Goldfarb, 1986), or a probabilistic representation of multiple candidate referents for the label (Smith & Yu, 2008). During the pre-naming phase of repeat Novel Label trials, the object pair could serve as a retrieval cue for the novel label. Once the novel label has been retrieved, the 22.5-month-olds may complete the mutual exclusivity inference, thus shifting attention to the novel object. Alternatively, the infant might retain a memory from the original Novel Label trials where the novel label is specifically associated with the novel object through the operation of mutual exclusivity. On Repeat trials, the
memory of this prior association could direct attention to the novel object.

In deciding between these alternative explanations, it is important to observe that the 22.5-month-olds do not have a preference for the novel object following the onset of naming during original Novel Label trials. Thus, there is no evidence that the novel label has increased the salience of the novel object or that a mapping has been formed. Therefore, it is more likely that the 22.5-month-olds have formed a memory of original Novel Label trials without specifically associating the novel label with the novel object. However, regardless of the range of explanations for the behaviour exhibited by the 22.5-month-old infants, all rely on a process which would support mutually exclusive responding. Under each explanation, the novel label causes a preference for the novel object on Repeat trials.

In conclusion, the present study provides unambiguous evidence from an IPL task that novel labels can direct infants’ attention towards novel objects, whereas a neutral linguistic phrase results in unsystematic looking behaviour. Although 22.5-month-old infants’ use of mutual exclusivity required multiple stimulus exposures, their behaviour during Repeat trials is evidence of a powerful ability to remember the contexts in which different novel labels are presented, without disruption from the intervening presentation of other objects and labels. Thus, infants’ use of mutual exclusivity to acquire novel word mappings from incidental exposures may be supported by the ability to retain information about novel labels and objects across such situations.

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References


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