Word-object associations are non-selective in infants and young children

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Abstract

For decades, theories of early word learning have assumed that infants are equipped with learning biases that help them learn words at a fast pace. One of these biases, called Mutual Exclusivity, suggests that infants reject second labels for name-known objects. Our first two experiments, with children and with infants, suggest that novelty preference during Mutual Exclusivity tasks should not be taken as evidence that associations between novel labels and name-known objects have not taken place. A third experiment, supplemented with computational modeling, ruled out cascaded activation patterns as alternative explanations and, instead, confirmed that word-object associations are non-selective throughout infancy and childhood.

Keywords: Mutual exclusivity; early word learning; cross-situational statistical learning

Introduction

Children learn words at a fascinating pace (Bloom, 2000). Researchers have suggested that infants are equipped with language learning biases that help them learn words efficiently (Markman, 1990). One such word learning bias, called Mutual Exclusivity (ME; Markman & Wachtel, 1988), suggests that each object has only one label. Markman and Wachtel (1988) found that children selected a novel object significantly more than a name-known object when hearing a novel label. The associations formed between novel labels and novel objects through ME have been shown to be retained, as Mather and Plunkett (2011) found that children were able to match novel labels with the matching novel objects they were exposed to during a learning phase. This provided evidence that ME can indeed be used to learn words. Yet, it did not address the question of whether infants reject additional labels for name-known objects or not.

In parallel, Smith and Yu (2008) found that when only name-unknown objects are present, infants retain multiple associations between labels and objects. According to their cross-situational statistical learning account (CSL), different word-object associations are being retained and their strengths evolve along with the presentation of labels and objects. Ultimately, a hierarchy of word-object associations is established through the differing numbers of co-occurrences between words and objects. The strongest word-object associations can be seen as providing a basis towards establishing robust patterns of word learning. This framework suggests that, contrary to ME, children are capable of forming more than one association between objects and words.

Further evidence brought a nuanced view to strict ME accounts. Learners were found to be able to overcome ME and performed above chance when forming two-to-one mappings in CSL-type experiments (Yurovsky and Yu, 2008). Kachergis, Yu and Shiffrin (2009) and Poepsel and Weiss (2014) found that although children performed better in one-to-one mapping, they readily violated ME if there was strong evidence that a new mapping was required.

Yet, Trueswell, Medina, Hafri, Gleitman (2013) found that children do not store all word-object associations. Instead, they make an initial guess and evaluate the validity of this guess in subsequent trials. If the guess is proven to be correct, then the association is strengthened. Otherwise, children will make another guess while discarding previously-made associations. This strategy was coined as a Propose-but-Verify hypothesis (PbV). In a more recent study, Stevens, Gleitman, Trueswell, and Yang (2016) refined their PbV hypothesis, and suggest that children store previous associations as references for future trials.

In our present contribution, we ask whether infants and young children accept second labels for *name-known* objects. To this end, we adapted a classic ME task, in which novel labels are being uttered while a name-known object and a novel object are being displayed. Strict ME accounts would suggest that children will map novel labels to novel objects, and that they will reject the formation of an association between novel labels and name-known objects.

In our adaptation, the learning phase featured two sets of ME training trials: in each set a novel label was uttered in the presence of a name-known object and of a novel object. During the testing phase, both novel objects used during training were shown together. If children were able to retain the associations learned during ME practice, they would be able to map each novel label to the matching novel object. This testing phase was aimed at verifying that ME can indeed be used to learn words, thus replicating Mather and Plunkett (2011). In another testing block, the two name-known objects used during ME were shown together, while playing one of the novel labels used during training. According to a strict interpretation of ME, children should not display preference for either objects, since they should have inhibited the formation of an association from the novel word to the name-known objects. In contrast, if children displayed a preference for the name-known object of the matching set, this would suggest that infants do not reject additional labels for name-known objects, and that they are non-selective when forming word-object associations. In other words, children would map the novel word with all objects present in the scene.

Thereafter, we will present three experiments aiming at refining our understanding of the formation of early word-object associations.

Experiment 1

Methods

Participants 174 children were recruited in Nottingham (UK) from which only data from English monolinguals (N = 148) was analysed, as bilinguals are expected to differ from monolinguals in ME-related tasks (e.g., Byers-Heinlein & Werker, 2009; Davidson & Tell, 2005; Houston-Price, Caloghiris, & Raviglione, 2010). The participants' age ranged from 4 years to 12 years (M = 7.36 years, SD = 2.06). Among them, 65 were male and 83 were female.

Stimuli The visual stimuli (pictures of 640 x 480 pixel) were obtained from Frank, Sugarman, Horowitz, Lewis, & Yurovsky (2016). The novel labels were "dax" and "modi" and both novel words and familiar words were embedded in the carrier sentence "Find the __!". Auditory labels were recorded by a female native English-speaker in an infant-directed manner.

Procedure The experiment was carried out on an iPad. The participants had to first complete a warm-up task, where they were instructed to tap on five dots appearing in random places, followed by five smiley faces presented on the screen of the iPad. After the warm-up task, the experiment was started. There were three experimental blocks, namely a Mutual Exclusivity (ME) training, a Word Learning test and a Selectivity test (see Figure 1).

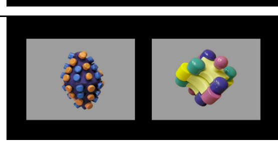
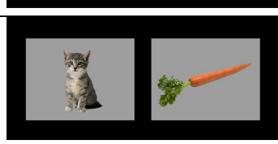
Block types	Image pairs	Auditory stimuli
ME training		Find the modi!
Word Learning test		Find the modi!
Selectivity test		Find the modi!

Figure 1: Example of different block types in Experiment 1.

In ME training, two sets of stimuli were used. Each of the sets consisted of one pair of images, one name-known image and one novel image, along with a novel label ("dax" and "carrot" for the first set, "modi" and "cat" for the other set). In each ME trial, one pair of images was displayed while the novel label was being played (embedded in the carrier sentence "find the __!"). We defined the target to be the novel object. Participants had the opportunity to learn two novel labels for the two novel images via ME. Each pair was repeated four times.

In the Word Learning test, both novel images (the "targets" in ME training) were displayed side-by-side while one of the corresponding novel labels used during training was played. These trials were repeated four times, such that both novel labels were uttered twice. The aim was to test whether the participant had formed an association between a novel label and the corresponding novel image; a prerequisite for word learning.

In the Selectivity test, the two name-known images (the "distractors" in ME training) were displayed side-by-side while one of the novel labels used for training was played. Target selection (i.e., tapping on the name-known image from the matching set) would provide evidence that an association between the name-known image and a second label was *not* inhibited during ME training. This block also consisted of four trials. The order of presentation of the Word Learning test block and the Selectivity test block was randomised across participants.

Results and Discussion of Experiment 1

As children were required to select an image out of two presented to them, binomial tests were run to measure the proportion of accurate responses as compared to chance (.50) in the different blocks. The proportion of accurate responses for the different blocks may be seen in Table 1.

Table 1: Observed proportion of accurate responses in different blocks

Auditory stimuli	ME training	Word learning test	Selectivity test
"dax"	.99***	.98***	.60*
"modi"	.98***	.96***	.69**

* $p < .05$. ** $p < .01$. *** $p < .001$ (1-tailed).

The results obtained provided evidence for the occurrence of ME during training, where the children selected the novel image upon hearing a novel word, thus replicating classical ME results (e.g., Golinkoff, Hirsh-Pasek, Bailey, & Wenger, 1992; Mather & Plunkett, 2011).

Children also performed above chance in the Word Learning test, indicating that they were able to form an association between the novel images and the novel words. This also replicates previous studies (e.g., Mather & Plunkett, 2011; Mervis & Bertrand, 1994;), which suggest that ME can indeed be used to learn words.

Crucially, it was also found that children were able to form associations between novel words and name-known objects, suggesting that word-object associations are non-selective.

Age was not found to correlate significantly in the Selectivity test (r = .113, p = .171), suggesting that younger infants going through a rapid expansion in their vocabulary may also be able to associate novel labels to name-known objects.

Experiment 2

Experiment 2 aimed at establishing whether *infants* are also non-selective when forming word-object associations. The design of Experiment 2 was similar to the previous experiment, with the main difference that infants were tested using an eye-tracker.

Methods

Participants Forty-three 21-month-old infants (M = 21.01, SD = 0.57) participated in the experiment (25 boys). Nine additional children were tested but excluded because of fussiness (4), failed calibration (4) or software problem (1). All participants were French native speakers recruited in the canton of Geneva, Switzerland.

Stimuli Four novel labels were created for the experiment: "pogalle", "pizelle", "nidoupe" and "loutade". The novel labels were all defined to be of feminine gender, so that no disambiguation could be applied before the onset of the word itself. In addition to the novel labels, eight familiar words were used throughout the experiment. All words were embedded in the sentence "Regarde la __!" (Look at the __!). All auditory stimuli were recorded by an enthusiastic French native speaker of Switzerland in a child-directed manner. Visual stimuli were photographs of objects on a light grey background which were extracted from the NOUN database (Horst & Hout, 2016).

Procedure The procedure of Experiment 2 was similar to Experiment 1 with the exception of two changes, listed thereafter. First, Experiment 2 was conducted with an eye-tracker. Thus, looking preference was analysed as opposed to target selection in Experiment 1. Second, another set of images and labels was used.

Infants sat on their caregiver's laps, in front of a flatscreen, approximately 70cm from the screen. An SMI RED500 eye-tracker recorded infants' fixations at a sampling rate of 500 Hz. The experiment started with a 5-point calibration and validation sequence. Upon successful calibration, the experiment started. The calibration procedure was repeated for infants who failed to go through all 5 points or if the validation revealed substantial deviations.

Analysis method Due to data loss in eye-tracking studies, measures typically used in intermodal preferential looking (IPL) paradigms, Preferential Target Looking (PTL) and Longest Look (LL) measures are not appropriate (Wass, Forssman, & Leppänen, 2014). A novel analysis was thus introduced similar to the one described by Maris and Oostenveld (2007). The approach is of the model-fitting type, whereby one does not merely compute the maximum likelihood estimates for a set of parameters; the models can also be tested whether or not they are significantly different from each other. The likelihood ratio test then provides the means for comparing the likelihood of the data under the hypothesis that infants are biased towards the target, against the likelihood of the data under the more restricted hypothesis (or null hypothesis) that infants do not have a preference for either the target or the distractor.

A binomial analysis is performed for every time step of every test trial in the post-naming phase, from 367ms after the onset of the target word (accounting for the time it takes infants to fixate the target object, see Swingley & Aslin, 2000) for 1500ms. For each time step the number of infants looking at the target is counted, as well as the number of infants looking at the distractor. The binomial test can reveal if an excess of infants looking at either the distractor or the target at that moment is likely to result from a biased looking behavior (e.g., that infants tend to look more at the target) or if an observed imbalance in the number of infants looking to the target and the distractor can be attributed to mere random variations or noise.

Results and Discussion of Experiment 2

Results Figure 2 depicts the looking preference of the 21-month-old infants when they were presented during the test phase with the two novel objects used during training (in black) and the two name-known objects used during training (in red). Vertical bars indicate the time steps for which an individual binomial test rejects the hypothesis that infants are not biased towards any object. In both test situations, hypotheses were rejected in favor of a bias towards the target.

Infants display a preference for the target and the log-likelihood that each point belongs to the distribution of unbiased simulated infants can be computed, as it corresponds to the negative square of the Mahalanobis distance (Mahalanobis, 1936). The log-likelihood L that the 21-month infants is unbiased equals L = 1.891 for the Word Learning test and L = -44.765 for the Selectivity test. The statistical relevance of this hypothesis can only be made from the comparison to another model; the biased model.

Log-likelihoods that the 21-month-olds belong to the distribution of simulated infants can be computed for each different bias, and one can estimate the maximum log-likelihood estimate, associated with the optimal bias; e.g., that accounts best for the data.

The maximum log-likelihood equals L = -0.010 for a bias towards the target when both novel objects are used during the Word Learning test and equals L = -0.003 for a bias towards the target for selectivity test.

Finally, the likelihood ratio test is applied. In the Word Learning test, the 21-month-old infants approach significance (p = .053). On the Selectivity test, the likelihood ration test shows that infants are significantly biased towards the target ($p < .001$). In other words, they have formed a second association between a novel label and a name-known object; 21-month-old infants also seem to be non-selective when forming word-object associations.

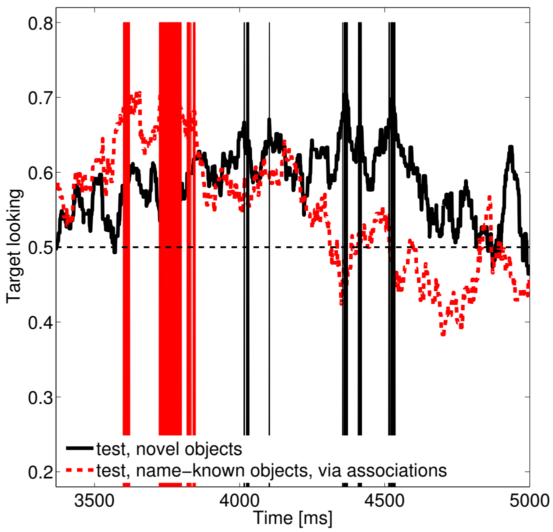


Figure 2: Proportion of infant target looking in the Word Learning test (in black) and in the Selectivity test (in red). Vertical lines highlight significant preference for the target according to a binomial test.

Experiment 3

In Experiment 1 and 2, children were found to be able to form associations between novel labels and name-known images. Yet, one cannot rule out that infants have formed an encyclopaedic mapping; i.e., they rely on the co-occurrence between the novel object and the name-known object to form an association between both objects. In turn, they may exploit this object-object association to select the name-known object when hearing the novel label, through cascaded activation from the novel label to novel object (through ME) and from the novel object to the familiar object (through the encyclopaedic mapping). To test if the association between the novel word and the name-known object is lexical or encyclopaedic, a new test, referred to as the Encyclopaedic test, was created. In this test, both novel images used during training were presented side-by-side, but the labels of the name-known distractors were played instead (see Figure 3). As the novel images were never displayed in the presence of these familiar labels, we would expect children's performance to be at chance level.

Methods

Participants 150 children were recruited at The University of Nottingham. Only data from the 124 English monolingual children (55 male, 69 female) was retained for analysis. Children were 3 to 12 years of age (M = 7.31 years, SD = 2.28).

Stimuli Visual stimuli were obtained from the same source as Experiment 1. The novel labels used were "pifo" and "dofa" paired with images of a ball and a cup, respectively.

Procedure The procedure was the same as Experiment 1 except for the sequence of the tasks. In Experiment 3, there were four blocks, namely the ME training, the Selectivity test, the new Encyclopaedic test and the Word Learning test. There were four trials in both the Selectivity test and the Encyclopaedic test but only two trials in Word Learning test. The order of the Selectivity test and the Encyclopaedic test was counterbalanced whereas the Word Learning test was always administered at the end of the experiment.

In the Encyclopaedic test, novel images used during ME training were displayed side-by-side while the names of the corresponding familiar images were played (see Fig. 3).

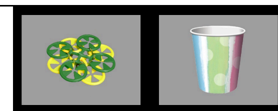
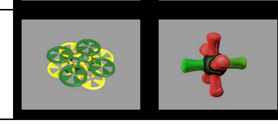
Block type	Image pairs	Auditory stimuli
ME training		Find the dofa!
Encyclopaedic test		Find the cup!

Figure 3: Example of the Encyclopaedic test.

Results and Discussion of Experiment 3

Binomial tests were run to measure the proportion of accurate responses as compared to chance (.50) in the different blocks. The results once more supported the presence of ME during training (all p's < .001) and that word-object associations are retained in the Word Learning test (all p's < .001).

However, and contrary to our hypothesis, children selected the target in the Encyclopaedic test (significantly above chance for "cup" (p = .001), and approaching significance for "ball", p = .063), suggesting that infants formed an encyclopaedic mapping between all items, rather than forming multiple associations at a lexical level between a name-known object and multiple labels. The only explanation is that children display evidence of cascaded activation, from the familiar name to the corresponding name-known object, and through the novel object it was paired with.

Does cascaded activation also explain results concerning the Selectivity test? Maybe children are strictly following ME; upon hearing the novel label, they activate the representation of the matching novel object (learned during ME) and select the name-known object that co-occurred with the novel object? How can we distinguish between the cascading and the non-selectivity explanations?

Let us look at correlations between the different experimental blocks. A strict ME account would suggest that lexical associations can only be formed between the novel label and the novel object during ME training. A stronger ME effect would translate into stronger associations between novel labels and novel objects. Through cascaded activation, novel label to novel object (ME) and from novel object to familiar object (through an encyclopaedic mapping), a strict ME account would suggest a positive correlation between performances in the ME training phase and performance in the Selectivity test.

In contrast, the hypothesis that word-object associations are non-selective (following the arguments of CSL) would predict that the novel label would also be associated with the name-known object. Accordingly, higher accuracy in the ME training block would suggest that children should spend more time on the novel object than at the name-known object, in turn leading to the formation of stronger associations between novel labels and novel objects but *weaker* associations between novel labels and name-known objects. Thus, if the associations between novel words and novel objects are non-selective, and that such associations take place at a lexical level, the accuracy score in ME training should correlate *negatively* with the accuracy score in the Selectivity test.

In our data, the accuracy score of ME training correlated positively with the Word Learning test (r = .232, p = .009), while correlations between ME and the Encyclopaedic test were not significant (r = -.075, p = .406), thus far consistent with both explanations. However, ME training results correlated negatively with performance during the Selectivity test (r = -.218, p = .015). The experimental results support the hypothesis that word-object associations are non-selective, and that the formation of association between novel labels and name-known objects take place at a lexical level. Next, we further scrutinise the above reasoning by constructing two simple computational models of Experiment 3.

Computational Models of Experiment 3

Two models were constructed, in order to compare a strict ME account with a non-selective account of the CSL type. In both models, associations are modulated based on co-occurrence of items presented simultaneously; between objects and labels, as well as between both objects. In each trial, previous association strengths define relative looking time towards each object via the application of Luce's forced choice rule (with a separation parameter of k=8). Looking time, in turn, modulate the magnitude of the association strength update, in a Hebb-like update rule (with a learning rate of 0.1). The associations between both objects are obtained by computing the product of the relative preference associated with each object. Similarly, indirect associations such as cascaded activation from the novel label to the novel object and the familiar object are computed through the product of the association strength between the novel label and the novel object and the association strength between the novel object and the familiar object.

The order of stimuli was identical in the model and for participants. 100 individual models were created for each hypothesis, and had a mean novelty-preference of 0.8, and Gaussian random variations of a standard deviation of 0.05. In the strict ME model, associations between novel labels and name-known objects were inhibited whereas in the non-selective model, such associations were permitted. Correlations between preference for the novel object during ME training and preference for the target object in each test block were computed.

As predicted, modelling results showed that a strict ME account sustains positive correlations between ME training and the Word Learning test (r = .89, p < .001) and between ME and the Selectivity test (r = .68, p < .001). In contrast, the non-selective model displays a positive correlation between ME training and the Word Learning test (r = .89, p < .001) but a *negative* correlation between ME and the Selectivity test (r = -.33, p < .001). The modelling results, along with the empirical results, provide additional evidence that children are non-selective when forming word-object associations.

General Discussion

While Mutual Exclusivity assumes that children associate only one word to one object, Cross-situation Statistical Learning accounts suggest that children maintain a hierarchy of word-object pairings established on the basis of co-occurrence of object and labels. These two theories have typically been tested using different experimental designs; while ME studies generally feature both novel and familiar objects, CSL studies typically present only novel objects. Our approach aims at testing both theories by using a Selectivity test, so as to examine whether children accept additional associations between a name-known object and a novel label.

In all three studies, we found that children tend to map the novel label to the novel object, replicating classic ME experiments, that infants tend to look at (or select) novel objects upon hearing a novel word.

We also replicated findings that associations between novel objects and novel labels are momentarily retained, thus providing a necessary basis towards the consolidation of word-object associations, and towards word learning (e.g., see Mather & Plunkett, 2011).

Yet, we argue that evidence of ME – a preference for a novel object when hearing a novel label – should not be taken as proof that associations between novel labels and name-known objects are suppressed. Experiment 1, with school-aged children, and Experiment 2, with 21-month-old infants, provided converging evidence that word-object associations are non-selective: children may well display evidence of ME during training, but they also show evidence that associations between novel labels and name-known objects are maintained during test blocks, and not inhibited as suggested by strict ME accounts.

Experiment 3 aimed at ruling out alternative explanations for the results observed in the first two studies. The introduction of an additional test block, the Encyclopaedic test, suggested that children displayed cascaded activation patterns. Yet, correlation analyses between the ME training phase and the different test blocks suggested that the pattern of results can be best explained if children are non-selective when forming word-object associations. Strict ME accounts would predict a positive correlation between ME training and selectivity test as children have to rely on cascaded activation to identify the target. In contrast, non-selective learning accounts would suggest that children displaying stronger novelty preference during ME training would display weaker associations between the novel label and the name-known object, thus leading to a negative correlation between ME training and the Selectivity test. The latter pattern of results was observed experimentally.

The finding that infants are non-selective in their formation of word-object associations sits well with other recent findings that infants are flexible in their interpretation of the meaning of novel words (Ramscar, Dye, & Klein, 2013) and that infants engage into cross-situational statistical learning with (multiple) objects in their visual field (Yu & Smith, 2011; Yurovsky, Smith, & Yu, 2013).

The very first stages of word learning taking place during ambiguous naming situations, such as in ME experiments or cross-situational statistical learning situations, do seem to be principled by low-level associationist mechanisms whereby multiple word-object pairings are being built. The hierarchy of word-object associations can then evolve across situations so that ultimately only relevant word-object mappings are retained. In sum, infants and children appear to be flexible when learning words and readily entertain the possibility that objects can have multiple names.

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