A Learned Label Modulates Object Representations in 10-Month-Old Infants

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Abstract

Despite substantial evidence for a bidirectional relationship between language and representation, the roots of this relationship in infancy are not known. The current study explores the possibility that labels may affect object representations at the earliest stages of language acquisition. We asked parents to play with their 10-month-old infants with two novel toys for three minutes, every day for a week, teaching infants a novel word for one toy but not the other. After a week infants participated in a familiarization task in which they saw each object for 8 trials in silence, followed by a test trial consisting of both objects accompanied by the trained word. Infants exhibited a faster decline in looking times to the previously unlabeled object. These data speak to the current debate over the status of labels in human cognition, supporting accounts in which labels are an integral part of representation.

Keywords: representation, word learning, language acquisition, linguistic relativity

Since Whorf (1940), scientists have been amassing evidence for a link between how we use language and how we represent the world. Much of this evidence comes from crosslinguistic studies which demonstrate that different (grammatical) structures interact with speakers' range of conceptual representations, for example space (Majid, Bowerman, Kita, Haun, & Levinson, 2004), time (Boroditsky, 2001) and color (Roberson, Davidoff, Davies, & Shapiro, 2005). The effects of language on representation have also been observed within a single language (e.g., Johanson & Papafragou, 2016; Son, Doumas, & Goldstone, 2010). For example, Lupyan (2016) asked adults to draw either "a triangle" or "a three-sided polygon" and found differences in the size and orientation of the shapes drawn by the two groups. While the strength and direction of this relationship has long been debated (for a review, see Slobin, 1996), there is consensus that language and representation interact in both perceptual and abstract domains.

Perhaps not surprisingly given the ubiquity of the relationship between language and representation, there is evidence that it begins early in development (for a review, see Robinson, Best, Deng, & Sloutsky, 2012). Recent work indicates that the relationship may begin at least at the same time as the onset of language learning. For example, looking time studies demonstrate that the presence of a label can direct 12-month-old infants' attention to commonalities between category exemplars (Althaus & Plunkett, 2015), and that labels can guide online category formation in infants in the first year of life (Althaus & Westermann, 2016; Plunkett, Hu, & Cohen, 2008). This work illustrates the effect of labels on online processing in these very young infants; however, whether such in-the-moment attention translates to differences in longer-term, learned representations in infants of this age is not clear.

While to our knowledge no study has explicitly examined the effect of learned labels on early representation, there has been a wealth of studies in early label learning and categorization. Infants show their first evidence of word learning from as early as six months (Bergelson & Swingley, 2012) and show signs of mapping novel words to objects in looking time tasks from around 10 months (Mather & Plunkett, 2010; Schafer & Plunkett, 1998; Werker, Cohen, Lloyd, Casasola & Stager, 1998). In the categorization literature, multiple studies show that long-term experience with everyday objects such as pets affects the category representations infants bring to bear in the lab (e.g., Kovack-Lesh, McMurray, & Oakes, 2014). In particular, in a carefully controlled training study Bornstein & Mash (2010) asked caregivers to train their 3-month-old infants with multiple exemplars of a novel object category via daily booklet-reading sessions. After two months, trained infants were invited to take part in a 3D object examining/categorization task, together with another group of untrained infants. The training changed infants' online behavior: relative to untrained infants with no previous experience of the novel category, trained infants showed no learning during a familiarization phase in which they were presented with previously-seen exemplars. Thus, evidence suggests that (a) word learned over time affect infants in-task responses and (b) category representations formed over time also affect these responses. Here, we ask about the relationship between the two; specifically, whether longer-term learning of labels in very early development can shape object representations.

Thus, in a training/familiarization study we asked parents of 10-month-old infants to train their children with two novel toy objects at home over a week (seven sessions), labeling one object (*labeled* object) but not the other (*non-label* object). We then recorded infants' looking times in a familiarization/preferential looking task using an eye-tracker. First, images of the two objects were presented individually, in silence, on a computer screen. We hypothesized that if object labels affect early object representations, we should observe differences in infants' looking times to the previously labeled and the non-labeled stimuli. We did not anticipate that these beginner word learners would show robust label-object associations (c.f., Horst & Samuelson, 2008). However, given that even partial knowledge of the mapping could influence infants' looking times (Yurovsky, Fricker, Yu, & Smith, 2014), after familiarization infants also saw a single preferential looking test trial in which both images appeared simultaneously, accompanied by the label.

Methods

Participants

Twenty-four 10 month-old infants (12 girls; M = 10m, 23d; SD = 14.15d, range = 9m, 26d – 11m, 13d) participated. All infants were typically developing and monolingual English learning with no family history of color blindness. Data from an additional four infants were excluded for fussiness (as defined by failure to start or complete the eyetracking task due to excess movement and/or crying); 2), experimenter error (1), and low eyetracker sample rate (< 35%; 1). All but three participants had completed all seven training sessions (7 sessions: 21; 6 sessions: 3). All participants returned for the second session approximately a week after the first (6 days: 2; 7 days: 19; 8 days: 3). Families were recruited by contacting caregivers who had previously indicated interest in participating in child development research. Caregivers' travel expenses for both visits were reimbursed and infants were given a storybook for participating.

Stimuli

Play sessions. 3D stimuli are depicted in Figure 1, and consisted of two age-appropriate wooden toy objects (castanets and two wooden balls joined with string), chosen because they are novel to 10-month-old infants (Fenson et al., 1994). Objects were approximately equal in size and were painted either red or blue using non-toxic paint. The label was *tanzer*, a pseudoword selected because it is plausible in English and was used in a previous developmental study (Horst & Twomey, 2012).

Looking time task. Familiarization stimuli consisted of digital photographs of the individual training objects presented centrally on a white background. Test stimuli consisted of photographs of the training objects presented side-by-side on a white background. The auditory stimulus for the test phase consisted of the phrase *Look! A tanzer!* spoken by a female speaker from the local area and recorded and edited for timing and clarity in Audacity 2.0.6. The phrase onset was at 4000ms, label onset at 5127ms, and label offset at 6000ms. Calibration and attention getter stimuli were a short video of a bouncing cartoon bird, accompanied by a jingling sound.

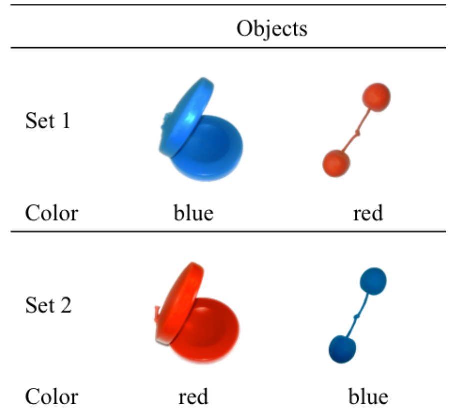


Figure 1: Stimuli used in the current study.

Procedure and Design

Visit 1: Play session. Objects' color and label were counterbalanced between participants such that for each object, half the infants received a blue exemplar and half received a red exemplar, with the constraint that each infant received one red and one blue object. Each exemplar served as the label object for half of the infants (*label* condition) and the no-label object for the other half of the infants (*no-label* condition).

First, the experimenter showed the caregiver the two objects and asked them whether their child had similar toys at home. Substitute items were available, however no child had prior experience of the objects. The experimenter then explained that she would demonstrate a play session, with the goal of teaching the infant a word for one of the objects. She then asked the caregiver to conduct a similar play session for three minutes, every day for a week and explained that they would be invited to return to the lab after seven days to take part in a simple looking-time study, which would involve the child watching static images on a computer screen.

The play session took place in a quiet, infant-friendly room with the caregiver present at all times. Before the session began, the experimenter emphasized that caregivers should not invent a name for the no-label object: only the label *tanzer* should be used, and only in reference to the labelled object. The experimenter then sat opposite the infant on the floor and introduced both toys by holding them in front of the infant and allowing the infant to take the toys in their own time. While the infant was looking at the toy the experimenter referred to them using a label or a pronoun as appropriate, for example "*Look, a tanzer!*" (label), "*Look at this*!" (no-label). During the course of the play session the experimenter explained to the caregiver that they should encourage their child to interact with both toys for an approximately equal amount of time, and that their child should be allowed to play with both toys at the same time (to encourage comparison; Oakes, Kovack-Lesh, & Horst, 2009). Infants heard the label approximately twice every fifteen seconds. After the play session caregivers were given the toys, written instructions and a sticker chart on which to record their play sessions.

Visit 2: Looking time task. The looking time task took place in a quiet, dimly-lit testing room. Children were seated on their caregiver's lap 50-70 cm in front of a 21.5" 1920 x 1080 computer screen at a 60 cm viewing distance. A Tobii X120 eyetracker located beneath the screen recorded the child's gaze, and a video camera above the screen recorded the caregiver and child throughout the procedure. Caregivers were instructed not interact with their child or look at the screen during the task to avoid biasing their child's behavior.

The eyetracker was first calibrated using a five-point infant calibration procedure. We displayed an attention-grabbing animation in the four corners and center of a 3 x 3 grid on a grey background accompanied by a jingling noise, and recorded infants' orientation to it with a key press. Calibration accuracy was checked and repeated if necessary ($n = 1$).

The attention-grabbing stimulus then appeared in the center of the screen. Immediately after the infant oriented towards the attention-grabbing stimulus, the experimenter began the familiarization phase using a keypress. Familiarization stimuli were presented individually in silence for 10 s. Infants saw eight identical images of the previously-labeled stimulus and eight identical images of the no-label trials, interleaved. Whether the label or no-label image was shown first was counterbalanced between children. Each trial was immediately followed by the attention-grabbing stimulus. Subsequent trials were advanced manually by the experimenter once the infant had reoriented to the screen, or began automatically after 5s.

Immediately following the familiarization trials a single test trial was presented in an identical manner. Left-right positioning of the objects (castanet/ball and label/no-label) was counterbalanced between children. The test trial was 12 s long, with auditory stimulus beginning at 4000 ms, label onset at 5172 ms and offset at 6000 ms. The test trial continued for 6 s post label offset to allow sufficient time to exhibit a response (Bergelson & Swingley, 2012).

Coding and data cleaning

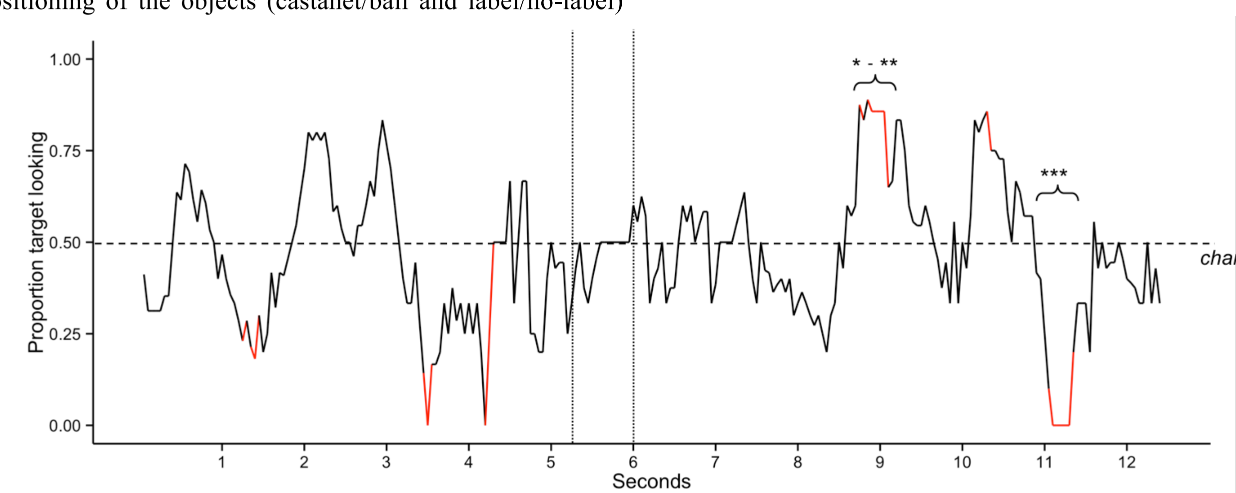
Timestamps for which the eyetracker failed to reliably detect either eye were excluded. Familiarization stimulus AOIs were centered on the single image and measured approximately 950 by 700 pixels. Test AOIs were centered on the two images and measured 766 by 435 pixels. Individual gaze samples were numerically coded (1 = AOI look, 0 = background look) to create a raw looking time measure.

Results

Familiarization phase

Individual looking time samples (numerically coded; 1 = AOI look, 0 = background look) were submitted to a binomial mixed effects model using the R package lme4 (version 1.1-10; Bates, Mächler, Bolker, & Walker, 2015). The model included fixed effects of trial (1 – 16) and label (centered; 0.5 = label, -0.5 = no-label), a trial-by-label interaction term, and random intercepts for participant and stimulus (this was the maximal model that converged; Barr, Levy, Scheepers, & Tily, 2013).

As is typical in looking time studies, target looking decreased across familiarization (main effect of trial: beta = -0.032, $SE = 0.0036$, $z = -8.83$, $p < .0001$), and did so fastest across training for no-label stimuli (trial x label interaction: beta = 0.014, $SE = 0.0072$, $t = 1.99$, $p < .05$). Specifically, mean looking per trial decreased from 5422ms on the first label trial to 2887ms on the last label trial, but 5696ms on



label onset: 5171ms
label offset: 6000ms

Figure 3: Proportion looking to the labeled target per 50 ms time bin during the test trial. Looking significantly different from chance (0.50) is indicated by a red line; systematic looking is indicated by asterisks; * $p < .05$, ** $p < .01$, *** $p < .001$.

the first no-label trial to 2733ms on the last no-label trial. Whether the stimulus has been previously trained with a label had no independent effect on overall looking times (main effect of label: beta = -0.033, *SE* = 0.069, *t* = -0.47, *p* = .63; cf. Capelier-Mourguy, Twomey & Westermann, under review).

Test phase

To establish whether infants responded to the auditory label we calculated the proportion of target looking out of all AOI on the test trial. Proportion target looking for each 50 ms time bin is depicted in Figure 3. Systematic fixation of target/distractor was defined where looking differed significantly from chance (0.50) for at least 150 ms (Holmqvist et al., 2011).

We defined the prelabeling phase from 0 – 6367ms, which includes 367 ms from label offset for preparation of the saccade (Swingley, 2009), and the postlabeling phase as 6368 ms to 12,000 ms. Infants showed no overall systematic preferences during either the prelabeling ($t(23) = -0.64$, p = .53; one-sample, chance = 0.5; all tests two-tailed) or postlabeling ($t(21) = -0.13$, p = .90; note two participants did not provide data in the postlabeling phase), and no difference between these phases ($t(21) = -0.65$, p = 0.52). However, as can be seen in Figure 3, fine-grained inspection of the unfolding of looking over time reveals that infants showed a late response to the label, increasing their target looking to above-chance levels 2.5 s after the label offset, in line with recent work examining 10-month-old infants' label disambiguation (Mather & Plunkett, 2010).

Discussion

In the current study, 10-month-old infants were trained over a week with two 3D objects and taught a novel label for just one of them. Infants were subsequently familiarized in silence with these objects in a looking-time study, and finally presented with a preferential looking trial in which they saw both objects accompanied by the label. Overall, infants maintained interest for longer in label than no-label stimuli. Critically, given that all 3D object training and familiarization for each object was identical except for the presence of the label during the play sessions, this study demonstrates that a learned label can affect infants' object representations. For the first time, then, this study traces the start of the relationship between language and representation to infants less than a year old.

Several studies have shown that infants' experience outside the lab affects their in-task performance. For example, Hurley & Oakes (2015) showed that 4-month-old infants with experience of pet cats and/or dogs at home paid more attention to the diagnostic features of cat and dog stimuli (i.e., the head) than their peers without pets at home. However, there was no difference in visual inspection strategies when stimuli were faces or vehicles. In these "pet" studies, stimuli were drawn from infants' everyday environment. Participants therefore came to the lab with substantial and prolonged experience (see also Perry, Samuelson, & Burdinie, 2014). However, when infants were trained with novel stimuli (e.g., Bornstein & Mash, 2010) similar effects of prior experience were found. Our results offer converging evidence that prior experience affects in-task behavior, showing that even a relatively small amount of additional linguistic experience – in this case, as little as 21 minutes over seven days – can affect infants' responses in-task.

However, infants in our study faced an added challenge. Not only did we ask them to encode two new objects, but we also asked them to attach a new label to one of them. Infants of this age are at the very beginnings of language acquisition (Fenson et al., 1994) and exhibit more fragile word learning than older children; for example, in a recent preferential looking study this age group increased looking towards the referents of frequently-heard words around 2.5 – 5.0 s after hearing labels (Mather & Plunkett, 2010). We replicate this finding: infants looked to the target 3 s after label offset. However, both objects were novel before training: our results demonstrate that 10-month-olds will treat a novel word as familiar after only a week of experience. Importantly, infants were not reminded of the novel word during their second visit, and did not receive a training session on that day. Thus, we can be confident that they responded to the label based on retrieval of the association from long-term memory; to our knowledge, this is the first study to demonstrate long-term novel word learning in infants of this age.

Mechanism

These results have several possible interpretations. Perhaps the most straightforward explanation is that the prior experience during training may have increased infants' attention to the labeled object at test. That is, despite our request to the contrary, infants may have spent more time engaging with one of the two objects during training. Infants of this age have a well-documented novelty preference (Fantz, 1964); that is, they will engage preferentially with items that are new (and therefore interesting), relative to items that are familiar (and therefore less interesting). The object infants had played with the most would be more familiar, and would therefore elicit less attention (lower looking times) during familiarization. Although we cannot rule out this possibility, we consider this unlikely. On this account, the fact that caregivers were teaching their child a label could unconsciously – or indeed consciously – bias them towards the labeled object, particularly as object names dominate maternal speech (Fernald & Morikawa, 1993). If anything, then, we would expect infants have more experience of the labeled than the no-label object. If so, the no-label object would have been most novel and should have elicited the longer looking times. In fact, we found the opposite.

Rather than resulting from the amount of experience infants received with each object, the patterns in looking time may stem from differences in infants' representation of the labeled versus the no-label objects. In fact, looking time differences were driven by a drop in looking to the no-label stimulus just over halfway through familiarization. This finding suggests that relative to the label stimulus, the no-label stimulus was more familiar to infants, begging the question of why the label stimulus should be most novel, and speaks to the recent debate concerning status of labels in object representations.

On the *invitations-to-form-a-category* (henceforth *invitations*) account, infants have an innate bias towards linking word representations with category representations. Importantly, the two are represented qualitatively differently. While object representations are learned from perceptual experience, labels play a top-down, supervisory role, serving as high-level, conceptual markers of category membership (Waxman & Markow, 1995). When a label becomes associated with an object it acts as an "invitation to form a category" indicating that it should also be applied to new items providing they are sufficiently similar; however labels are not integrated into object representations. In sharp contrast, the *labels-as-features* account assumes that labels are simply features of perceptual object representations (Gliozzi, Mayor, Hu & Plunkett, 2009; Sloutsky & Fisher, 2004). Labels are integrated into object representations in the same way as color or shape; thus, the word *strawberry* and the color red will have the same qualitative status in a speaker's representation of the fruit. More recently, Westermann & Mareschal (2014) argued that labels are represented separately from objects, but critically, in the same representational space. On this *compound-representations* account, labels are neither simple features of object representations nor a different type of structure altogether. Instead, labels are perceptual representations which become associated with object representations over time.

In the context of the current study, the invitations account predicts that there should be no difference in looking to the labeled and no-label stimuli, because labels do not affect individual object representations[1]. This is not what we found. On the labels-as-features account, if an object appears consistently with a label, the label is incorporated into the object representation. When the object appears without the label, then, what infants experience is different from the learned representation. Thus, infants' greater looking to the labeled stimulus is in line with the labels-as-features account. However, the compound representation account also makes this prediction: when a compound label-object representation is formed, a missing label will increase the novelty of the object relative to its representation. Note that we are not claiming that the learned label renders the representation more robust, but rather that the label becomes incorporated into (invitations account) or associated with (compound representations) the representation over learning. Given the present data, then, we must remain agnostic as to whether labels are encoded as part of or separately from object representations. However computational work is underway to tease apart the labels-as-features and compound-representations accounts (e.g., Capelier-Mourguy et al., 2016).

[1]Although this account does predict that learned labels shape *category* representations; we are currently testing this prediction.

Overall, the current study provides converging evidence that long-term learning experience has a marked effect on in-lab behavior – a critical point for our interpretation of the wealth of existing infant studies. We also demonstrate word learning from limited exposure in infants at the earliest beginnings of the language acquisition journey. Most importantly, however, we show for the first time that language has long-term effects on nonlinguistic representation before the end of the first year, demonstrating that language affects the way we see the world right from its very beginnings.

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