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The role of representational strength in verbal updating: Evidence from 19- and 24-month-olds

Martyna A. Galazka [a,*], Patricia A. Ganea [b,*]

[a] Uppsala Child and Baby Lab, Department of Psychology, Uppsala University, S-751 42 Uppsala, Sweden
[b] Dr. Eric Jackman Institute of Child Study, University of Toronto, Toronto, Ontario M5R 2X2, Canada

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ABSTRACT

The current research investigated the role of object familiarity in children's ability to update the representation of an absent object via language. In Study 1, the degree of object familiarity was manipulated by the amount of time children were exposed to an object. The results showed that when 19- and 24-month-olds were minimally exposed to the object, only the 24-month-olds were able to incorporate newly heard information about it by selecting the new version of the object. Studies 2 and 3 demonstrated that the younger children's failure to update is due to their failure to activate an object's weak representation in working memory. When the object's weak representation was reactivated (by seeing a depiction of the object) prior to the language input, the younger children successfully updated their representation of the object. The findings are discussed in light of the graded representation account.

Introduction

Children, like adults, must often rely on other people to acquire information about things that are not perceptually available. Once they master language, much of children's learning is based on what they are told, and often new information concerns things that they have not directly experienced such as the existence of bacteria and a novel event that occurred across the world (Harris, 2007, 2012). Until recently cognitive development research has focused on how children learn from first-hand

* Corresponding authors.
E-mail addresses: martyna.galazka@psyk.uu.se (M.A. Galazka), patricia.ganea@toronto.ca (P.A. Ganea).

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observation, with relatively little attention to how children structure and adjust their knowledge on the basis of others' verbal input (Gelman, 2009).

The ability to integrate new information about things that are absent is, above all, based on our capacity to retrieve and maintain the memory representation of the object while the new information is received. In this sense, object memory representation is a mental depiction of an object that was created when the object was initially perceived and that can be retrieved from long-term memory when not directly observed (Kosslyn, Thompson, & Ganis, 2006). Stronger representations of objects are more likely to support these processes than weaker representations (Munakata, 2001; Munakata, McClelland, Johnson, & Siegler, 1997). One way to strengthen an object's representation is through repeated exposure to the object in question, which changes the pattern of neural activity representing that stimulus (Munakata et al., 1997). Research on object search has shown that infants are better at maintaining object representations when repeatedly presented objects are hidden. For example, 7.5-month-olds search more frequently for a familiar object when it is hidden even though they show a distinct preference for a novel object when it is visible (Shinskey & Munakata, 2005).

Research on infants' ability to respond to *names* referring to absent objects has shown a similar effect of representational strength on the ability to bring the representation of the object to mind upon hearing its name. One-year-old infants can respond to the name of an absent object, indicating that they can retrieve the object's representation from memory and maintain it active to initiate a response (searching or looking for the object) (Ganea, 2005; Saylor, 2004). However, factors that determine the strength of a representation (e.g., familiarity with the referent) affect whether infants respond to such references. For example, 1-year-old infants gesture significantly more toward the door after hearing the name of a familiar person, such as the child's father, who recently left the room (Ganea & Saylor, 2013a). But when such references are made about a recently met person, for example one of the research assistants, infants do not react in the same way. Nevertheless, infants respond to the name of the person when he or she is in view, indicating that they had learned the person's name. These findings suggest that familiarity with the referent plays a critical role in child's ability to activate its representation when the referent is absent. With age, infants are better able to build stronger representations of objects and they are better able to maintain such representations in working memory under higher task demands (when they have not seen the object for a long time before hearing its name again or when the object is mentioned in a novel context) (Ganea & Saylor, 2013a, 2013b). For example, 16-month-olds can respond to both new and familiar people when mentioned in their absence, and they can do so even when the test is delayed after the person's departure (Ganea & Saylor, 2013a).

Activating an object's representation on hearing its name is a critical step enabling children to learn new things through language. Recent research has shown that the ability to update an absent object's representation following new verbal input emerges during the second year of life (Ganea & Harris, 2010, 2013; Ganea, Shutts, Spelke, & DeLoache, 2007). In one study, 19- and 22-month-olds learned the proper name ("Lucy") for a target object ("frog"), which was then removed from children's view (Ganea et al., 2007). While the target object was in another room, children were told about a change in a property of the object (i.e., that Lucy had become wet). To test whether children revised their representation of Lucy based on newly received information, children were asked to indicate Lucy from three test choices: a wet frog, a dry frog, and a wet pig. The 22-month-olds successfully picked out the wet frog, whereas the 19-month-olds did not. Instead, the 19-month-olds were more likely to update when the new information was given to them in the presence of the toy.

One unexplored possibility, which resonates with the previous findings on absent object reference, is that younger children may be able to update their representation, but only when their initial representation of the referent is strong. The role of representational strength has been illustrated for infants' ability to update on the basis of *visual* information. In some versions of the A-not-B task (Piaget, 1954), strong object representations are necessary for children to correctly search for the object; however, when task demands are lessened (e.g., by using gaze measures), weaker object representations suffice for correct performance (Hofstadter & Reznick, 1996; Munakata et al., 1997; Wellman, Cross, & Bartsch, 1986). Similarly, when updating requires a change in the quantity of objects represented, stronger representations may be required. By 5 months of age, infants can use visual information about a change in quantity to update their representation of occluded objects (Koechlin, Dehaene, & Mehler, 1997; Wynn, 1992). If they see a bunny become hidden behind a screen and then see a second bunny do the same, they show surprise when only one bunny is revealed (Wynn, 1992). However, the ability to visually update seems to be influenced by whether children's representation of the initial quantity is still the focus of attention at the time the change is presented. If, for instance, the task requires children to reactivate the initial quantity in one location after their attention was switched to a second location, 11-month-olds fail to update (Feigenson & Yamaguchi, 2009). Thus, although the ability to visually update an object's representation is present by children's first birthday, developments in the ability to activate and maintain memory representations at the time the new information is given affect the extent to which children can revise representations on the basis of visual information.

The goal of the current article was to examine whether the degree of representational strength affects the extent to which children update their representation of an absent object via language. The specific question was whether repeated exposure to an object would influence toddlers' ability to use new verbal information about the object to revise its representation. Previous research has shown that 19-month-olds did not update their representation of an absent object when they heard about a change in a property of the object (Ganea et al., 2007). Here, we asked whether 19-month-olds would show evidence for verbal updating given a stronger representation of the object. A group of 24-month-olds was also included because past research has shown that by this age children can successfully update mental representations with verbal information about a property change. Studies 2 and 3 further explored whether the difficulty that 19-month-olds have with updating weak representations is due to a difficulty in activating the object's representation in its absence or to a difficulty in manipulating that representation when the object is not in view.

Study 1

In the first study, toddlers were introduced to two identical stuffed animals (two gray cats). One toy was labeled with its proper name, "Max," so that it could be later referred to in its absence. The second of the two toys was introduced as "Max's friend." In all conditions, children were exposed to Max while his friend remained visible but out of the child's reach. All participants were randomly placed in two experimental groups, which varied exclusively by the amount of exposure to Max. Then, while the toys were out of view, the experimenter provided children with new verbal information about Max's appearance (i.e., that he got painted green). Because previous findings showed that children were not influenced by the property change alone, with almost none picking a distractor object that also displayed the new property (Ganea et al., 2007), the children in this study were asked to choose between two target objects: the original gray Max and the new green Max. We hypothesized that if children failed to incorporate the new information about Max, they would pick the gray cat—the one they had been exposed to during familiarization. However, if they accurately updated their representation of Max, they would choose the new green Max.

Method

Participants

The participants were 70 toddlers in two age groups: 24-month-olds ($n = 38$, $M = 24.3$ months, range = 22.0–27.9; 21 girls and 17 boys) and 19-month-olds ($n = 32$, $M = 19.1$ months, 17.1–21.7; 19 girls and 13 boys). An additional 15 infants were tested but subsequently excluded due to failure to pass the comprehension check (six 19-month-olds and three 24-month-olds), uncooperativeness (5), or parental interference (1). All participants were randomly assigned to one of two experimental groups: high exposure (24-month-olds, $n = 21$; 19-month-olds, $n = 16$) and low exposure (24-month-olds, $n = 17$; 19-month-olds, $n = 16$). Participants were recruited through a database of public birth records in the greater Boston area of the northeastern United States, and the majority of them were White and middle-class.

Materials

Materials consisted of three identical stuffed animals (two gray cats and one gray cat that was spray painted green), one stuffed duck approximately the same size as the cats, 12 small distractor toys, a small container filled with green paint, and a paintbrush.

Procedure

The procedure involved six phases: the introduction, the exposure phase, the label phase, the comprehension check, the acquisition of new information phase, and the test phase (see Fig. 1 for a schematic depiction of the procedure). The procedure was conducted by an experimenter and an assistant. The experimenter showed the child the objects, performed the comprehension check, and asked the test questions. The assistant kept time during the exposure phase and provided new information about Max.

Introduction phase. The purpose of this phase was to introduce the child to the test objects. Upon entering the testing room, the child was seated at a small table and the experimenter showed the child a box containing one of the two gray cats. The experimenter introduced the gray cat from the box as "Max," saying, "Look here! This is Max." Next, the experimenter took an identical gray cat, introduced it as "Max's friend," and placed it on a shelf diagonally in front of the child while saying, "And this is Max's friend. He will sit here, and he will watch us play." The second toy, Max's friend, was introduced so that the child would not be surprised by the sudden presence of a similar looking second toy during the test phase.

Exposure phase. The purpose of this phase was to familiarize the child with Max. The duration of the exposure phase was approximately the same across conditions, with the only difference being in the

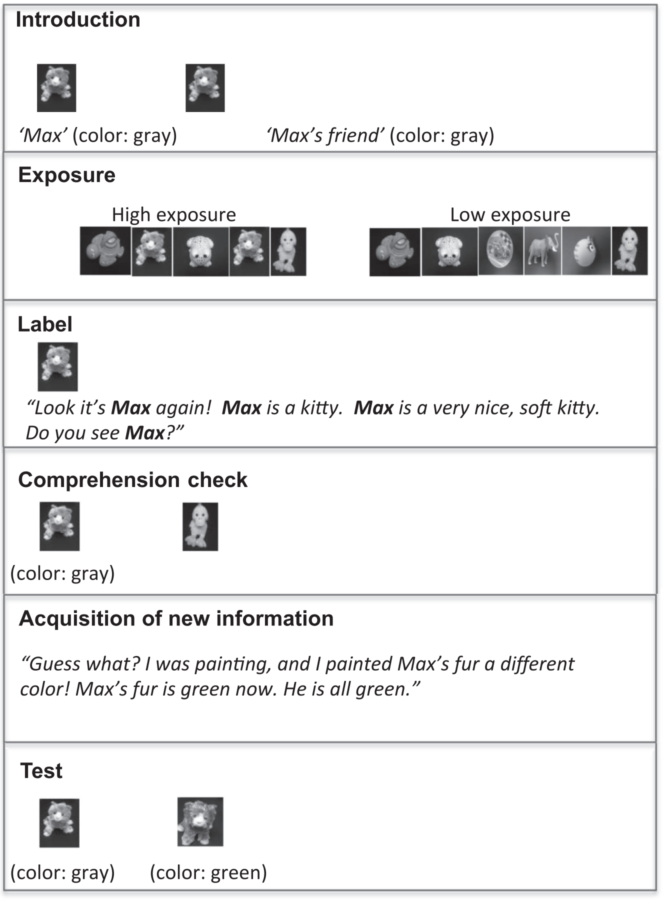

Fig. 1. Schematic depiction of the procedure.

number of times that children saw Max and heard him labeled. In the high-exposure condition, the child was presented with distractor toys and Max interchangeably over 12 10-s trials, resulting in six presentations of Max and six presentations of different distractor toys. During each toy presentation, the assistant kept track of time and gently tapped the table every 10 s. To ensure that the child attended to each toy, the experimenter made a comment about each toy. For the distractor toy trials the experimenter exclaimed, "Look at this!", whereas for the trials in which she introduced Max the experimenter provided the toy's name, "Look! It's Max." In the low-exposure condition, the child was presented with only the 12 distractor toy trials for 10 s each. In both conditions, the last distractor toy was a stuffed yellow duck that was later used during the comprehension check.

Label phase. Following the exposure phase, the child was reintroduced to Max. The purpose of this reintroduction was to ensure that both the high- and low-exposure groups knew that the name Max referred to one of the gray cats. During this phase, the experimenter brought out Max and mentioned his name four times ("Look, it's Max again! Max is a kitty. Max is a very nice soft kitty. Do you see Max?"). By the end of the label phase, the high-exposure group had heard the name Max spoken 11 times (one time during the initial introduction, six times during the exposure trials, and four more times during the label phase), whereas the low-exposure group had heard the name five times (one time during the initial introduction and four times during the label phase). For the high-exposure group, the total exposure to Max was approximately 100 s (exposure trials and label phase). For the low-exposure group, the exposure time was approximately 19 s (label phase only).

Comprehension check. During the comprehension check, the experimenter placed Max and a yellow duck on the table next to each other but far enough apart to make the child's choice obvious. The yellow duck was used during the comprehension check because it was approximately the same size and was plush like Max. The experimenter then asked the child to pick Max.

All children included in the final sample passed the comprehension check. To pass, the child needed to either choose Max two consecutive times or on two of three questions. When the child was incorrect after the first question, the experimenter pointed to the gray Max and said, "Look, this one is Max. Yes, this one." The experimenter then repeated the comprehension question, switching the sides where Max was presented. If the child did not choose Max after feedback, the experimenter continued with the procedure but the child's data were excluded from the final sample.

In the 24-month-old group, 27 of 38 children (71%) passed the comprehension check by selecting Max correctly on the first two trials, whereas 11 of 38 children (29%) passed the comprehension check by selecting Max on two of three questions. Of these 11 children, eight were in the high-exposure group and three were in the low-exposure group. In the 19-month-old group, 19 of 32 children (60%) passed the comprehension check by selecting Max correctly on the first two trials, whereas 13 of 32 (40%) passed it by selecting Max two of three times the question was asked. Of these 13 children, 10 were in the high-exposure group and three were in the low-exposure group.

Attribution of new information phase. The purpose of this phase was to provide the child with new information about the target object. Following the comprehension check, all children were invited to accompany the experimenter to another room to look at some other toys. Before they left, the child was told that the assistant was going to stay behind and paint. At that time, the assistant took out a small container of green paint, a paintbrush, and some paper and began painting. To make sure that the child was aware of the paint, she invited the child to look on as she painted, allowing the child to look into the container, to dip the paintbrush into the paint, and to paint on a piece of paper. As the child was leaving the room, the assistant repeated that she was going to stay behind and paint.

After approximately 2.5 min, the assistant came to get the child from the second room, announcing that she had something to show the child in the first room. Once they were back in the testing room, the experimenter, the assistant, and the child stayed in the outer part of the room, which separated the place where the previous testing took place with a curtain. Importantly, the table and the toys, which the child saw during testing, were behind the curtain, invisible to the child. While in the outer space, the assistant informed the child of the change. She said, "Guess what? I was painting, and I painted Max's fur a different color! Max's fur is green now. He is all green." The experimenter then reinforced the information: "Did you hear that? Max got green paint on his fur! He's all green now!" The experimenter then invited the child to go see the animal ("Do you want to go see Max? Let's go see Max!"). The experimenter then moved the curtain, exposing the testing table with two animals: a green cat and a gray cat.

Test phase. The test phase was designed to determine whether the child would identify the target animal as one that had undergone a property change—in this case, the color change. The new target animal was entirely spray-painted with green paint. Although completely green in appearance, it was obvious that the paint was added onto the animal, with old gray parts of the fur being detectable on closer inspection of the toy. The new target animal (green cat) and the original target animal (gray cat) were placed on a small table. The placement of the new target and the original target toy was counterbalanced across participants; half of the children saw the target toy on the left, and the other half saw it on the right. During the test, the experimenter asked the child to show the target animal ("Can you show me Max?"). Then, to clarify the intentional choice, the experimenter asked the child to give her the target toy ("Can you give me Max?"). For some of the younger children who had difficulty in responding to those two prompts, the experimenter used a more tangible request, asking children to put Max in a small shoebox.

Coding

Videotapes of the exposure and test sessions were coded by two naive coders to measure the total amount of exposure time to the target and to identify children's intentional choices during the test phase. The total exposure time was measured as the sum of exposure to the object during the exposure and label phases. For each age group, there was a significant difference between exposure times in the low- and high-exposure conditions: 24-month-olds ($M_{\text{low exposure}} = 17.4$, $M_{\text{high exposure}} = 91.7$), $t(32) = 17.95$, $p < .01$; 19-month-olds ($M_{\text{low exposure}} = 20.3$, $M_{\text{high exposure}} = 98.67$), $t(30) = 17.56$, $p < .01$.

At test, only intentional acts on the target toy were judged as responses—either by deliberately pointing to a toy or picking it up and giving it to the experimenter. For some of the younger children, the intentional choice was encouraged by asking them to "clean up" the toys and to put Max into the box where he belonged ($n = 7$). For three of these children this was done to encourage an initial choice because none was made, and for four of these children the box was used as a third prompt when the choice was unclear or when the child picked both toys. In the final sample, five children (four 19-month-olds and one 24-month-old) initially chose both animals. In these cases, the experimenter repeated the question one more time. At this point, all five children settled on one of the two animals. Children who simply explored or touched either toy were not coded as making an intentional choice. Instead, these children were encouraged to give the experimenter Max by repeating the prompt. The coding was the same for all studies. Two naive coders coded all of the tapes. The level of agreement between the coders for the three studies ranged from 81.3% to 100% (Cohen's kappas = .60–1.00, *ps* < .01). Disagreements were resolved by a third naive coder.

Results and discussion

When presented with the original target toy (gray Max) and the target object with the new property (green Max), most 24-month-olds selected the green target object regardless of condition (see Fig. 2). In this age group, 16 of 21 children (76.2%) in the high-exposure group picked the green Max, $\chi^2(1, N = 21) = 5.762$, $p = .016$, as did 13 of 17 children (76.5%) in the low-exposure group, $\chi^2(1, N = 17) = 4.765$, $p = .029$. Thus, in both conditions the 24-month-olds updated their representation of the object with the newly received information. The 19-month-olds performed differently as a function of condition. Whereas 13 of 16 children (81.25%) in the high-exposure group correctly chose the green Max, $\chi^2(1, N = 16) = 6.250$, $p = .012$, only 6 of 16 children (37.5%) in the low-exposure group did so, $\chi^2(1, N = 16) = 1.000$, $p = .317$. This difference was significant, $\chi^2(1,32) = 6.348$, $p = .029$.

These results show that by 24 months of age, children can update their representation of an absent object with newly heard information about the object. They can do so whether their initial exposure to the target object is 20 or 100 s. In contrast, 19-month-olds' ability to update was affected by the amount of exposure to the object. In this age group, children in the high-exposure condition were

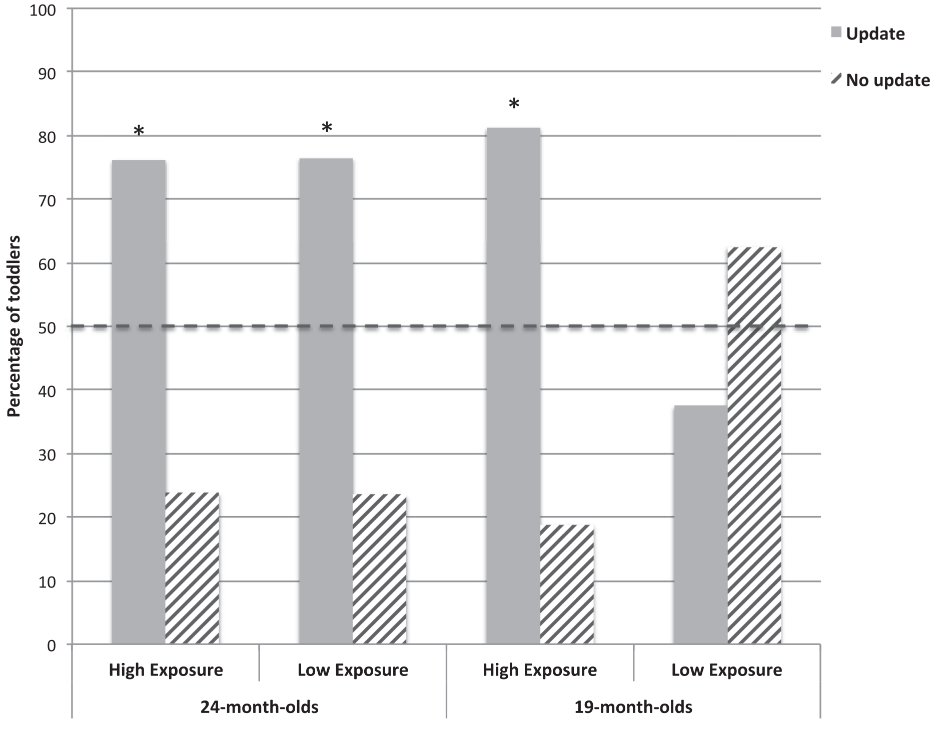

Fig. 2. Percentage of toddlers who selected the changed toy (green Max) as a function of age and condition (Study 1). An asterisk (*) indicates performance significantly different from chance (50%).

more likely to update their object representation than children in the low-exposure condition. These findings indicate that early in development children's ability to update an object's representation based on new verbal information depends on the initial strength of their object representation.

An important question to address next has to do with why the 19-month-olds failed to update in the low-exposure condition. One possibility is that because their representation of the object was weak, children could not activate it at the time they heard the new information about the object in its absence. Another possibility is that children did activate their object representation but failed to bind the new information with their existing representation. To test between these two possibilities, in Study 2 we tested a new group of 18-month-olds in the low-exposure condition. Children in this group were briefly shown a picture of gray Max before they were given new information about it in order to activate the toy's representation in its absence.

Study 2

Method

Participants

The participants were 16 18-month-olds (M = 18.4 months, range = 17.3–19.6; nine girls and seven boys). An additional seven infants were tested but were excluded from the final data set due to parental interference (n = 2) or failure to pass the comprehension check (n = 5).

Procedure

The introduction phase, exposure phase, label phase, and comprehension check were identical to those in the low-exposure condition in Study 1. Similar to Study 1, after the comprehension check, the child was shown the paint and was told that the assistant would stay in the testing room and paint. The child then left the room with the experimenter. After approximately 3 min, the child was brought back to the testing room. At this point, the procedure differed from Study 1. Once the child was back in the testing room, the experimenter showed the child a cardboard box that was covered with a lid. The experimenter encouraged the child to open the box and look inside. Inside the box was a 4 $\times$ 6-inch colored photograph depicting the original gray Max. The assistant took out the photograph and pointed to it while saying, "Do you remember Max? Yeah, Max!" She then replaced the picture back in the box, put the lid back on the box, and proceeded with the attribution of new information phase from Study 1. Thus, children received the new information about Max's new color immediately after they saw a picture of the original toy.

The average exposure time to the toy referent was approximately 20.8 s, excluding the photograph presentation. There was no significant difference between exposure time to the real toy in the low-exposure condition in Study 1 and that in Study 2, $t(47) = 1.63$, $p = .109$. The exposure to the photograph was approximately 10.6 s.

Results and discussion

The results suggest that the brief exposure to the photograph of the referent prior to presenting new information about the referent aided the 18-month-olds' ability to update via language when their initial exposure to the object was minimal. Most of the 18-month-olds (12/16, 75%) selected the toy with the new property, $\chi^2(1, N = 16) = 4.00$, $p = .046$ (see Fig. 3). The 18-month-olds in the low-exposure condition in Study 2 were more likely to update after their brief exposure to the object compared with the 19-month-olds in the low-exposure condition in Study 1 (6/16, 37.5%), $\chi^2(1,32) = 4.571$, $p < .073$. The only difference between these two groups was that in Study 2 children's representation of the toy was reactivated before the new information was given. The performance level of the 18-month-olds in Study 2 approached the performance level of the 24-month-olds in Study

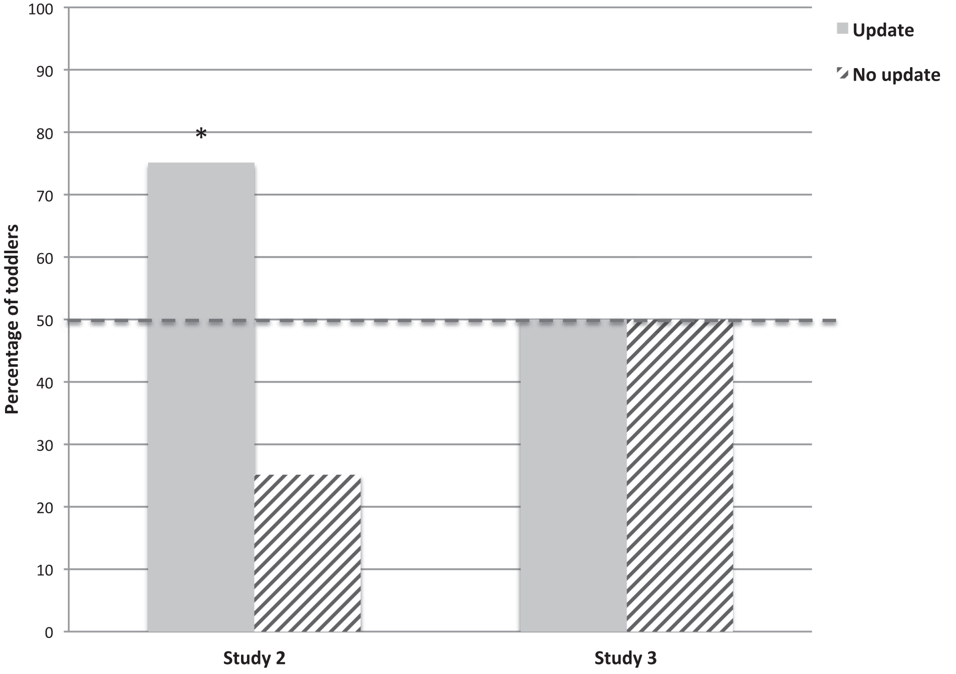

Fig. 3. Percentage of 18-month-olds who selected the changed toy (green Max) in Study 2 (object exposure + picture) and Study 3 (picture only). An asterisk indicates performance significantly different from chance (50%).

1 in both the low-exposure condition, $\chi^2(1,33) = .010$, $p = 1.000$, and the high-exposure condition, $\chi^2(1,37) = .007$, $p = 1.000$.

An important question to address has to do with whether 18-month-olds in Study 2 formed a new representation of the object based on the photograph alone. In other words, does the photograph serve to reactivate the previously formed representation of Max, or does it simply allow children to form a new representation of Max that they would immediately integrate with the new input? To address this question, we tested another group of 18-month-olds for which the exposure was limited only to the photograph without previous exposure to the object itself. Presumably, if 18-month-olds can readily form an object representation from the photograph exposure alone, they would update based on the new information they received because this representation was formed just prior to the new input and, thus, no reactivation was needed. If, however, they fail to integrate the new information in their representation of the toy, this would indicate that the prior exposure to the object is necessary and that the photograph in Study 2 was in fact a means to activate the previously formed representation of Max.

Study 3

Method

Participants

The participants were 12 18-month-olds ($M = 18.2$ months, range = 18.1–19.2; six girls and six boys). An additional two infants were tested but excluded from the final data set due to parental interference ($n = 1$) or because the child never made a choice of toys during the test phase ($n = 1$).

Procedure

The procedure involved three phases: the paint familiarization phase, the attribution of new information phase (with photo exposure as in Study 2), and the test phase. Overall, the procedure was similar to that in Study 2 with the exception that there was no previous exposure to the real toy prior to the test phase. Because the exposure phase was eliminated, only the assistant conducted the study.

Paint familiarization phase. After the child and parent entered the testing room, the study began with the presentation of the paint. As in Studies 1 and 2, the assistant took out a small container of green paint, a paintbrush, and some paper and began painting. To familiarize the child with paint, she invited the child to look on as she painted, allowing the child to look into the container, to dip the paintbrush into the paint, and to paint on a piece of paper. The paint familiarization lasted approximately 1 min.

Attribution of new information phase. Following the paint familiarization phase, the assistant brought over a box, same as in Study 2, which contained a 4 × 6-inch colored photograph of the original gray Max. The assistant then encouraged the child to open the box and to look inside, after which the assistant took the photograph out and pointed to it while saying, "Look here! This is Max. Yes, his name is Max!" She then put the picture back in the box, replaced the lid, and proceeded to provide new information about Max in a manner identical to the attribution of new information phase of Study 1. However, because in this group the assistant was the only experimenter, the wording was adjusted so that the number of times children heard the toy's name and the word "green" were the same as in Studies 1 and 2. Consequently, the assistant said, "Guess what? I was painting and I painted Max's fur a different color! Max's fur is green now. He is all green. Yes, he got green paint on his fur. Max is all green." The average exposure time to the picture was approximately 5 s. After the assistant provided the child with new information, she invited the child to go see the animal ("Do you want to go see Max? Let's go see Max!").

Test phase. Unlike in Studies 1 and 2, the test phase for this study was conducted in a room adjacent to the testing room. Therefore, after the attribution of new information phase, the assistant opened the door to the next room to reveal a small table on which there were two cats: one green cat and one gray cat.

Results and discussion

The results suggest that when children are simply shown a depiction of a referent and then learn about a new property of the referent, without previous exposure to the object itself, 18-month-olds do not integrate the new property into their representation of the referent. The 18-month-olds' performance was at chance, with 6 of 12 children (50%) selecting the toy with the new property and 6 of 12 children (50%) selecting the version of the toy as shown in the photograph, $\chi^2(1, N = 12) = .000$, $p = 1.000$ (see Fig. 3). These results indicate that the picture exposure in Study 2 aided children's ability to retrieve a previously formed memory representation of the toy rather than simply leading to the formation of a new representation. These results point to a new direction for future research investigating when and how children become capable of forming and updating object representations on the basis of symbolic exposure and language.

General discussion

The current research demonstrates that by 2 years of age children can readily update an absent object's representation with new verbal information regardless of the amount of exposure to the object. The performance of the 24-month-olds in this study provides evidence for a combination of cognitive abilities at this age: the ability to readily form new memory representations after brief exposure, the ability to activate and maintain those representations when the object is not in view, and the ability to use newly heard information to adjust the content of representations accordingly.

In contrast, the 18- and 19-month-olds in this research were able to update an absent object's representation via language only when the representation of the object was strong as a result of a long initial exposure. Accordingly, having a weak object representation, following a relatively minimal exposure to the object, resulted in children's failure to update. The results of Studies 2 and 3 suggest that 19-month-olds' failure to update in Study 1 can be attributed to their difficulty in bringing to mind the object at the time the new information was received rather than to their inability to adjust representational content on the basis of verbal information. When the 18-month-olds in Study 2 were shown a photograph of Max, and thus were helped in activating its representation before receiving the new verbal information, their performance improved. When children were presented with the photograph alone (Study 3), their performance was at chance. This pattern of performance suggests that exposure to the photograph in Study 2 served as a means to activate the previously formed representation rather than as a means to form a new representation of the referent at the time the new verbal input was received.

An important issue to address concerns novelty preference. One possibility is that children selected the changed toy because of a preference for novel things. This is not likely for several reasons. First, previous studies examining the ability to update property change via language (Ganea et al., 2007) clearly demonstrated that children are not attracted by property change alone. In the study by Ganea et al. (2007), only 2 of the 40 children tested chose the distractor object (wet pig), showing that a great majority of children tested learned which category animal is the target and did not base their choice on the property change alone. Second, if novelty preference had influenced choice in the current study, this preference should have been evident across conditions. However, the 19-month-olds displayed significant differences based solely on the amount of exposure they had to the target object.

The present findings provide support for the graded representation account (Munakata, 2001) according to which representations that are more enduring, due to familiarity with the object, can withstand various visual barriers (such as in the A-not-B task during infancy) or temporal delays between the time the object is seen and when it is referenced again. Increased exposure allowed the 19-months-olds in the current research to perform at a level comparable to that of the 24-month-olds. When their exposure to the object was low, and thus their representation of the object was weak, the younger children had difficulty in updating (Study 1). Our results are consistent with previous findings that strong representations support retrieval and maintenance of an object's representation in memory (Ganea & Saylor, 2013b; Shinskey & Munakata, 2005) and that weak representations benefit from the support of recent activation (in this study, seeing a picture of the referent before hearing new information about it aided children's ability to manipulate its representation).

With age, infants' representations get stronger and processes involved in updating, such as activation and maintenance of representations in working memory and integration of information across modalities, become more efficient (Clearfield, Diedrich, Smith, & Thelen, 2006; Schutte, Spencer, & Schöner, 2003). It is also possible that with age the ability to readily form new, strong representations is a more efficient process (Perone & Spencer, 2013). Thus, the performance of the 24-month-olds in Study 1 may reflect faster formation of robust memory representation at that age even following relatively short exposure time.

The results of Study 2 indicate that difficulty with updating a prior representation with information received at a subsequent time may be due to poor activation and maintenance of the existing representation and not to difficulty in integrating the new information. Once the object representation was reactivated, 18-month-olds were able to use the verbal input about the object. This finding is consistent with previous results showing that 11-month-old infants have difficulty in visually updating their representation of object quantity when their attention has switched elsewhere and they have to reactivate their initial representation of quantity (Feigenson & Yamaguchi, 2009). Thus, developments in the ability to activate and maintain memory representations affect the extent to which children can revise representations on the basis of visual or verbal information. In the future, it will be important to systematically study the interaction among representational strength, modality in which the new information is received, and the temporal lag between initial representation and delivery of new information to fully understand how infants' representational capacity constrains their ability to use newly received information.

The type of paradigm used in the current study may have especially influenced the object's representational strength. Modeled from the stimulus adaptation paradigm used by Shinskey and Munakata (2005), object representation was gradually strengthened through an activation and reactivation of the object's representation through brief individual presentation of the object several times for a specified time (Grill-Spector, Henson, & Martin, 2006; Henson & Rugg, 2003). This paradigm allowed children to focus their attention entirely on the object, removing the object before children's attention weaned and presenting it again with renewed interest and focus. While other studies may have provided greater temporal exposure to the stimuli (Ganea et al., 2007), the context within which the stimuli were presented did not provide the same attentional focus as in the current study, which may have influenced the quality of exposure and therefore the object's representational strength.

An important direction for future research is to investigate children's ability to form and update representations of novel objects based on symbolic exposure to a referent. Does the type of experience with a referent affect the quality of infants' representation and in turn their ability to manipulate that representation? For example, recent research shows that children as young as 15 months can learn labels for depicted objects from picture books (Ganea, Pickard, & DeLoache, 2008). However, pictures and objects allow for different affordances, and it would be interesting to know whether the quality of memory representation of a referent in memory depends on how the referent is introduced: verbally or visually (i.e., through a picture) and whether this would in turn affect children's ability to revise those representations with new information. Recent evidence with adults indicates that the neural mechanisms involved in processing two-dimensional images versus three-dimensional objects are different (Snow et al., 2011); thus, it is not clear whether updating of these different types of representations would proceed in a similar manner.

An additional future direction for research is to further examine the extent to which updating representations of different strength levels may depend on the type of revision involved—whether the revision requires enriching a representation with new information or a complete deletion of preexisting representation (Ganea & Saylor, 2013a; Harris, 2012). Because aspects of strong representations are more entrenched, it is possible that it is harder to completely delete or replace aspects of strong initial representations but easier to enrich them with new information. Literature on adult learning suggests that this may indeed be the case. In one study, adults were asked to learn new facts about famous individuals. It was found that adults were able to learn and retain more facts about these individuals as a function of how familiar they were with them (Van Overschelde & Healy, 2001), with stronger representations facilitating adults' ability to enrich them with new information. Conversely, literature on belief revisions in adults suggests that the more entrenched beliefs are, the less prone they are to revisions (Doyle, 1991).

Recent research with children suggests that children, like adults, may have difficulty with the updating process when it involves deletion of old information (Ganea & Harris, 2010, 2013). Even at 24 months of age, children are prone to commit errors in updating when previously stored information about an object becomes invalid and therefore is in conflict with current information. Despite being told that an object had been moved from Location A to Location B, 23-month-olds often commit perseverative errors - they search for the object at Location A (Ganea & Harris, 2010, 2013). As proposed by Ganea and Harris (2013), children fail to actively maintain the new information about the location change in working memory because they have to disregard conflicting information about the object's prior location. The updating process in the current research required the addition of a new fact (the toy had green paint on it) to an existing representation rather than a complete revision of a specific feature of the object, which would be in conflict with the new information. This is a fascinating question for future developmental research; is it harder for young children to delete/replace specific aspects of strong initial representations but easier to enrich them with new information?

To summarize, the current research indicates that the ability to add new information to an absent object's representation is in place by 24 months of age regardless of the amount of exposure to the referent. At younger ages, however, longer exposure and thus stronger representations are required to enable children to more easily activate and maintain those representations at the time the new information about the object is received.

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