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Brief Report

24-Month-olds and over remember novel object names after a single learning event

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ABSTRACT

In the context of word learning, it is commonly assumed that repetition is required for young children to form and maintain in memory an association between a novel word and its corresponding object. For instance, at 2 years of age, children are able to disambiguate word-related situations in one shot but are not able to further retain this newly acquired knowledge. It has been proposed that multiple fast-mapping experiences would be required to promote word retention or that the inferential reasoning needs to be accompanied by explicit labeling of the target. We hypothesized that when 2-year-olds simply encounter an unambiguous learning context, word learning may be fast and maintained in time. We also assumed that, under this condition, even a single exposure to an object would be sufficient to form a memory trace of its name that would survive a delay. To test these hypotheses, 2- and 4-year-olds were ostensively taught three arbitrary word–object pairs using a 15-s video sequence during which each object was manually displayed and labeled three times in a row. Retention was measured after a 30-min distractive period using a forced-choice procedure. Our results provide evidence that declarative memory does not need repetition to be formed and maintained, for at least a 30-min period, by children as young as 2 years. This finding suggests that the mechanisms required for extremely rapid and robust word acquisition not only are present in preschoolers

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with developed language and cognitive skills but also are already operative at a younger age.

Introduction

Word learning is a complex cognitive process that involves the acquisition, integration, and retrieval of multimodal information, a skill that infants progressively acquire during development. In general, around the middle of their first year of life, children realize that words can specifically refer to objects in the environment (Bergelson & Swingley, 2012; Kuhl, 2004; Oviatt, 1980). However, during this early stage of word acquisition, linking the name of a new object is a time-consuming and repetition-dependent process for pre-vocabulary spurt infants. In the literature, essentially all previous studies have used 10 or more ostensive pairings between the token word and its referent to induce infant comprehension on immediate test trials (Gurteen, Horne, & Erjavec, 2011; Hollich et al., 2000; Oviatt, 1980; Schafer & Plunkett, 1998; Woodward, Markman, & Fitzsimmons, 1994). In the context of cross-situational statistical learning, it has also been shown that 12- to 14-month-olds need multiple experiences to detect regularities and to solve the indeterminacy problem (Smith & Yu, 2008).

However, overall, the literature clearly suggests that there is a noteworthy developmental step in infants' ability to master word learning processes during the second year of life (Gurteen et al., 2011; Hollich et al., 2000; McMurray, 2007; Reznick, 1990; Werker, Cohen, Lloyd, Casasola, & Stager, 1998; Woodward et al., 1994). Indeed, generally after the vocabulary spurt, children seem to require only a limited number of exposures to comprehend the meaning of a new word (e.g., Bion, Borovsky, & Fernald, 2013; Carey & Bartlett, 1978; Golinkoff, Hirsh-Pasek, Bailey, & Wenger, 1992; Halberda, 2003; Mervis & Bertrand, 1994; Spiegel & Halberda, 2011; Waxman & Booth, 2000) and they also develop inferential reasoning abilities that enable them to rapidly infer an object from a new word by logically excluding familiar objects (i.e., "referent selection").

Memory formation of newly learned words in young children

Despite this, children need to retain this knowledge for future use, which is crucial for word learning to be successful (see Wojcik, 2013, for a review). The handful of studies investigating how word learning translates into more permanent memory traces during childhood suggest that repetition-based processes are still needed for post-vocabulary spurt children to retain the names of novel objects. For instance, there is a consensus that a unique referent selection event is not enough to demonstrate retention in 24-month-olds (Bion et al., 2013; Horst & Samuelson, 2008). According to the *dynamic associative word learning model,* children may solve referential ambiguity within the context of a single inferential event, but building long-lasting linkages requires multiple exposures with the elements to map (McMurray, Horst, & Samuelson, 2012). In other words, at 2 years of age, word learning from ambiguous situations would be a slow process (Bion et al., 2013). Intriguingly, when the objects inferred by logical exclusion were also ostensively labeled several times by an experimenter holding them up (Horst & Samuelson, 2008, Experiment 2), 24-month-olds recognized the associations after a 5-min delay. This suggests the aptness of ostensively naming the objects, as well as using nonverbal gestural cues such as pointing and holding up the objects, to foster 24-month-olds' pairing recall after a minimum delay (Horst & Samuelson, 2008; see also Booth, McGregor, & Rohlfing, 2008).

Unfortunately, although ostensive labeling has been largely studied in preschoolers in several language acquisition domains such as shape bias, this word learning method has received only little attention in the context of word retention in children over 2 years of age (e.g., Gordon & McGregor, 2014). Could it be that a unique learning event that uses direct instruction is enough to induce a memory trace that survives a delay? If so, could it be that unambiguous learning situations such as

ostensive labeling overcome learning from inferential reasoning, which has been shown to be unlikely to yield retention at that age?

To address these questions, in this study we examined whether, in the context of ostensive naming, 2-year-olds are able to retain, for at least a half-hour delay, the names of objects after a single brief exposure to these objects. Using a touch-screen interface, three novel objects were presented in isolation and labeled during short video sequences. Participants' retention was tested after a 30-min distractive period using a three-alternative forced-choice (3-AFC) procedure. Four-year-olds, who have a relatively more mature hippocampal system, were also included for comparison as well as a group of adult participants, naïve to the purpose of the study, to confirm the feasibility of this stringent design and to provide the ceiling performance at test.

If ostensive labeling is truly a powerful learning method in 2-year-olds and over, we hypothesized that a single learning event would suffice for our participants to remember the novel word–object associations at test. We expected the 4-year-olds to outperform the 2-year-olds, and we expected the adults to outperform both child groups.

Method

Participants

A total of 23 children aged 24 months (14 girls; M_{age} = 24 months 2 days, *SD* = 20.13 days) with a mean productive vocabulary score of 73.5% on a 100-word checklist (IFDC, a French adaptation of the short MacArthur–Bates devised by Kern, Langue, Zesiger, & Bovet, 2010) (range = 10–99%) completed this study. Data from 4 additional children were not included in the analyses due to fussiness (n = 3) or failure to engage in the task (n = 1). Also included were 20 children aged 4 years (8 girls; M_{age} = 4 years 2 months, *SD* = 3.96 months). One additional 4-year-old was excluded from the analyses due to a systematic selection of the top image on all test trials. Children were mostly recruited from child-care centers and preschools. A control group composed of 20 adult participants (13 women; M_{age} = 31 years 4 months, *SD* = 10.12 years), who were naïve to the purpose of the study, was used for comparison with the children. All child and adult participants were native French speakers. This study was approved by the French ethical committee for the protection of human participants. All participants and their legal caregivers gave oral and informed written consent, respectively, before experimentation.

Stimuli

Prior to the task, color photographs of five familiar and eight novel stimuli were shown to the parents to ensure that their children were familiar with the known objects and were unfamiliar and unable to label the novel ones. Novel stimuli consisted of manually modified toys that do not have a proper label in French. The investigator randomly chose three familiar and three novel objects.

Auditory stimuli consisted of 12 bisyllabic child-adequate pseudowords generated based on the work by Dohen, Vilain, Loevenbruck, Rochet-Cappellan & Gillet-Perret, 2016. Auditory stimuli were recorded by a female native French speaker and normalized for intensity using Audacity. The durations of all pseudowords were highly similar (*M* = 490.17 ms, *SD* = 62.17). Parents also appraised the novelty of these pseudowords prior to the task, and the investigator then randomly assigned a pseudoword to each novel object to learn. Pairings of pseudowords and objects were counterbalanced across participants.

Learning stimuli

During the learning session, stimuli were presented in short video sequences, each lasting precisely 15 s, during which the object was manually displayed, briefly manipulated by the hand of an experimenter, and labeled three times in a row using an ecologically valid prerecorded labeling phrase before disappearing (e.g., "Regarde! Ça c'est un *rivou,* un *rivou,* un *rivou*" ["Look! This is a *rivou,* a *rivou,* a *rivou*"]).

Testing stimuli

During testing, stimuli consisted of color photographs of the three novel objects simultaneously displayed on the screen in a triangular configuration. Then, 1500 ms after trial onset, participants heard audio recordings asking them to touch the images corresponding to the novel words. One of three prerecorded utterances was randomly assigned for each trial.

Apparatus

The experiment was run using a Windows Surface Pro 4 (display size = 12.3 inches, display resolution = 2736 × 1824 [5 MP]) and generated from a self-developed program under Python software. The touch-screen was placed at arm's length facing children using an articulated mount securely attached on a table.

Procedure

During the experiment, children sat on a booster seat next to their parents or on their parents's lap facing the touch-screen. Participants provided answers by touching the screen. Parents were instructed to avoid interactions with their children but could encourage them to respond if necessary. For the adult group, participants were instructed to test and evaluate an application designed for children. The study began with three warm-up trials. During this habituation phase, participants watched the videos of the familiar objects and subsequently completed a 3-AFC session involving the three familiar items (one test trial per object). Because some pilot experiments found that some children could demonstrate a strong bias toward a specific position or object irrespective of the label pronounced, each of these three warm-up trials was correct answer blocked in the sense that only a correct answer could launch the following trial. This warm-up session was immediately followed by the novel word–object pairs learning phase. Each novel object was introduced to the participants only once (Fig. 1). After learning, children were engaged in playing activities and/or in non-interfering experiments (e.g., music, art) in the experimental room for a 30-min period (M = 29.42 min, SD = 5.10). With such a delay, the children moved onto something totally different, and this should rule out the possibility of thinking about what they just learned. During the same corresponding period, to get the adults' minds occupied, participants from the adult control group needed to complete distractor tasks. Retention test trials for novel objects used the same 3-AFC procedure as with the familiar warm-up trials except that novel objects served as the target three times in an interspersed manner and any answer could trigger the following trial. The position of the target object was pseudorandomized with the constraint that the target could not appear at the same screen position for more than two consecutive trials. There were no time constraints on responding.

Results

To determine whether children were able to form a reliable memory trace of randomly paired word–object associations after a single exposure to each object, we tested performance in a retention test session 30 min after learning. Touching responses were automatically recorded and analyzed as a measure of retention. Among all 63 participants, two 24-month-olds and one 4-year-old failed to complete the task, but because each novel object appeared as the target at least once, we did not exclude their data from the analyses. For each age group, the level of performance, calculated as the proportion of trials for which each child correctly identifies the referent, was compared with levels expected by chance (i.e., 33%) in binomial tests.

Results showed that 24-month-olds performed significantly above chance (M = 43.9%, SD = 18.28, 95% confidence interval [$CI_{95\%}$] = [36.81–50.93], p = .002) with a medium effect size (Cohen's d = 0.60). The 4-year-olds similarly chose the target object significantly more often than would be expected by chance (M = 44.3%, SD = 20.99, $CI_{95\%}$ = [36.41–51.44], p = .004) with a medium effect size (Cohen's d = 0.54). As expected, adults performed highly above chance level (M = 73.89%, SD = 33.87, $CI_{95\%}$ = [66.83–80.14], $p < 2.2 \times 10^{-16}$) with a large effect size (Cohen's d = 1.21), confirming the feasibility

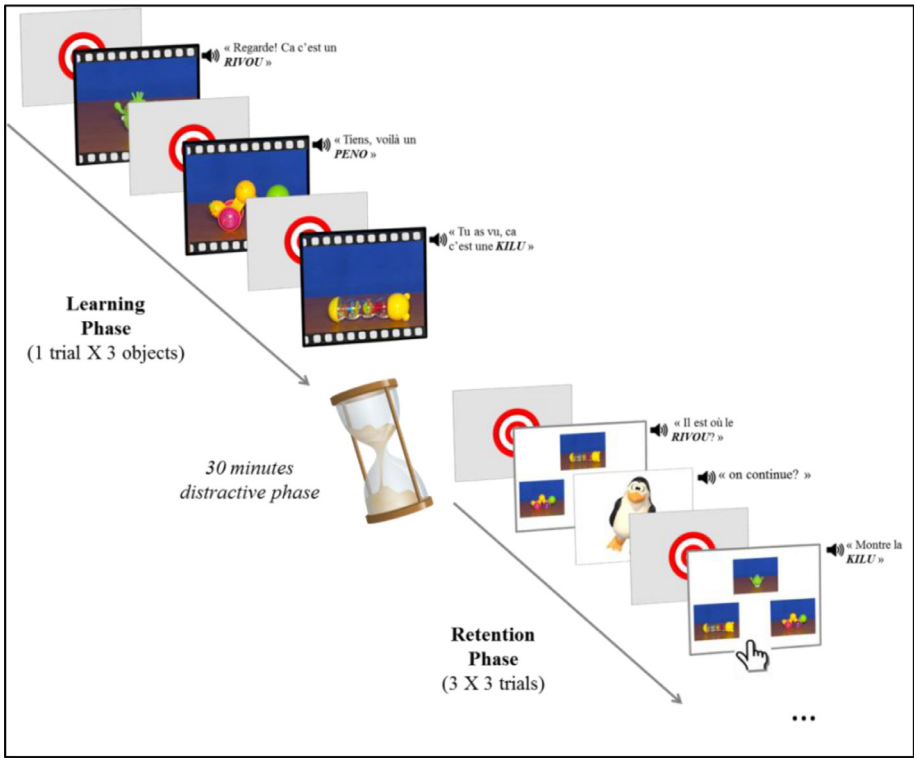

Fig. 1. Illustration of the experimental design. Participants were presented with three novel objects paired with arbitrary chosen labels. Participants initiated each trial by pressing a red button in the center of the touch-screen. During learning, each object appeared only once in a 15-s video sequence. After a 30-min distractive period, retention was tested using a three-alternative forced-choice procedure consisting of nine trials. No feedback was provided; however, to keep participants focused, each test trial was followed by a 3-s GIF animation showing a moving penguin accompanied by a stimulating sentence such as "on continue?" ["should we continue?"].

of this task. Altogether, our results showed that participants in the three age groups successfully remembered the novel word–object pairs for which they had a single learning experience (Fig. 2). Complementary analyses revealed that the duration of the distractive period (M = 29.42 min, SD = 5.10) did not influence these results given that participants with shorter retention delays did not exhibit higher retention scores, $F(1, 61) = 0.72$, $R^2 = .01$, $p = .39$.

Next, to assess whether performance improved with age, a generalized linear mixed model (GLMM) was conducted, including age as the fixed effect (2-year-olds vs. 4-year-olds vs. adults), repeated measures on individuals as a random effect, and the performance as binomial data. The model indicates that adults outperformed both 2- and 4-year-olds (GLMM, z value = 4.75, $p < .001$), but no significant difference was observed between the 2- and 4-year-old groups (GLMM, z value = 0.20, $p > .05$). Complementary analyses revealed no significant effect of age within age groups, although the performance of adults had a tendency to decrease with age, $F(1, 18) = 4.00$, $R^2 = .18$, $p = .06$.

We also investigated whether the language level of our 2-year-old participants influenced their ability to retain the associations given that the well-defined vocabulary spurt phenomenon typically occurs between 18 and 24 months of age. The IFDC, the 100-word checklist adapted for French children, was used as an estimate of the vocabulary production skill of the 24-month-olds. Most of them had already passed the vocabulary spurt by the day of the experiment (mean IFDC score = 73.5% ± 26.3); 14 of the 23 child participants had an IFDC score at or above the 50th percentile). No significant

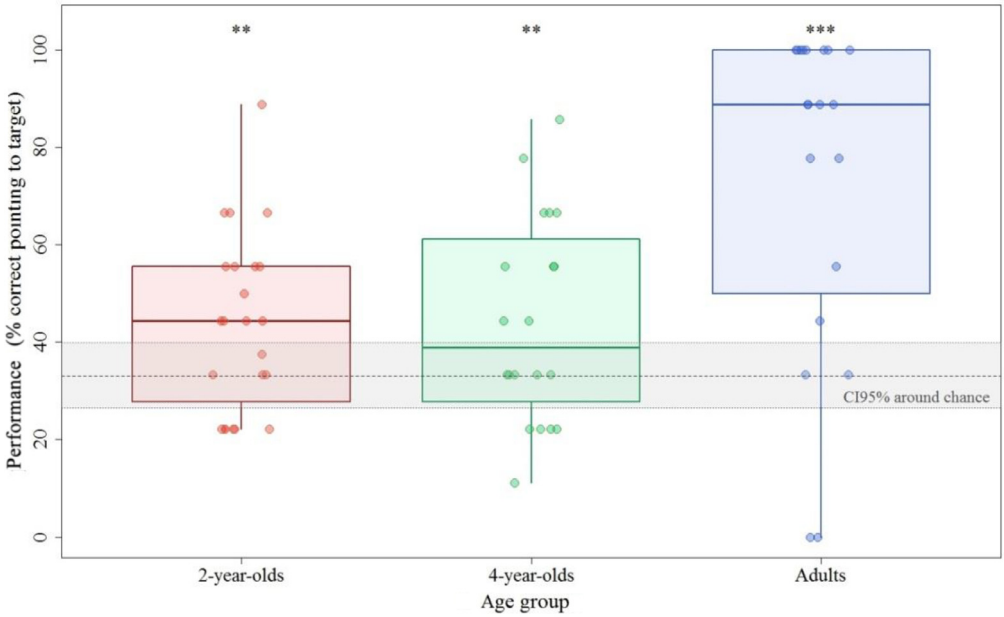

Fig. 2. Performance during retention. Percentages of hits (successful touching of the target object) during the forced-choice retention task are shown. Binomial tests indicate that each age group performed significantly above chance (**p < .01, ***p < .001). Box plots show the median (solid line). Dashed lines represent the 33% chance level (dark gray) and the 95% confidence interval (CI95%) around chance (light gray). Individual mean performance is depicted in circles (2-year-olds: left [red]; 4-year-olds: middle [green]; adults: right [blue]).

correlation was found between the performance of the 24-month-olds at test and their IFDC vocabulary production scores (r = .05, p = .32).

Finally, our device recorded the time participants took to respond after label onset (i.e., delay between label onset and tactile response, whether the response was correct or not). On average, 24-month-olds needed 5.54 s (SD = 3.07) to provide their answers, 4-year-olds took 3.01 s (SD = 1.19) to respond, and adults took 2.42 s (SD = 1.19) to respond. A one-way analysis of variance (ANOVA) revealed significant differences among age groups, $F(2, 60) = 13.80$, $p = 1.17 \times 10^{-5}$. Follow-up Tukey post hoc tests indicated that all age groups differed between each other in their mean time to respond except that between 4-year-olds and adults (adjusted p = .64).

Discussion

This study asked whether children aged 2 and 4 years can remember the names of newly learned objects after a 30-min delay following a single unambiguous learning event. To this purpose, we developed a tightly controlled experimental design that introduced each novel object once to the participants and measured retention using a 3-AFC procedure, which offered a straightforward measure of whether the names of the objects had been retained.

Word learning paradigms: Ostensive naming versus inferential reasoning in 2-year-olds

We showed successful retention in children as young as 24 months, indicating that, in the context of ostensive naming, a unique learning event is sufficient to form and maintain in memory the association between both a novel word and a novel object.

Previous research showed that when 24-month-olds were facing a learning procedure that required them to map novel objects onto their referents by logically excluding familiar objects, they failed to retrieve the fast-mapped words 5 min after learning unless the targets were also ostensively taught several times by an experimenter holding them up (Horst & Samuelson, 2008). Consequently, inferential learning per se has been modeled as a slow word learning process in 24-month-olds (Bion et al., 2013; McMurray et al., 2012). Here, we demonstrated that learning words from unambiguous situations that include explicit naming is fast and effective at that age. Our work provides evidence against a slow word learning mechanism and shows that, under adequate age-fitted learning strategies, learning from one event is possible during early childhood.

Developmental shifts in efficacy of the learning methods

In contrast to our expectations, the ostensive naming procedure employed in the current experiment did not reveal significant differences in performance between 2- and 4-year-olds, although 4-year-olds had shorter response times. One explanation is that the efficiency of the learning methods may evolve during development. We suggest that, whereas ostensive naming is very efficient at inducing word learning at 2 years of age and probably enhances retention more efficiently than learning from inferential reasoning, the opposite pattern may be implemented in older children. Indeed, a previous study revealed that inferential learning overcomes ostensive naming at 3 years of age (Zosh, Brinster, & Halberda, 2013). The authors of that study had already suggested that a developmental shift in the contexts that support word learning may exist if younger children truly outperform in unambiguous learning contexts. Our findings are compatible with this assumption.

Underlying mechanisms

In the literature, it has been suggested that early in life declarative memory is primarily built on repetitive learning events spaced in time; thus, such memory would first be semantic (Newcombe, 2015). Moreover, associative Hebbian theories have been proposed as the main process supporting word learning (McMurray et al., 2012). Therefore, our finding that early in life retention can occur without the need for repetitive experiences, or the need for a night of sleep or a nap to consolidate the newly acquired information, raises obvious questions about the underlying mechanisms. We hypothesize that the fast declarative memory formation reported here may be attributable to brain maturational processes that occur around 2 years of age (e.g., the peak of synaptic density in the dentate gyrus is reached around 2 years of age) (Jabès & Nelson, 2015; Seress, 2001) and/or to general improvements in attentional resources and language. Indeed, most of our 2-year-old participants had already undergone the vocabulary spurt by the day of the experiment. In a previous study that used the exact same design, we found that 18 months pre-vocabulary spurt children required many more learning trials to retrieve the object names after an equivalent intervening period (Remon et al., 2018), which is in accordance with the findings reported in the literature.

However, we cannot exclude the possibility that repetition happened during the 15-s video clip. It might be that the 15-s learning event involved in the end multiple brief visual repetitions (e.g., each eye movement = one repetition) and that each of them contributed to the strengthening process of the neural circuitry. Obviously, this issue highlights the extreme difficulty of defining *repetition,* its time frame, and its boundaries within the different sensory modalities, especially within the visual domain. Here, we considered a single event as the visual depiction of a novel referent, that is, from its appearance on the screen to its disappearance. To comply and facilitate comparison with the referent selection learning procedures used in previous studies (e.g., Horst & Samuelson, 2008), the object was labeled few times during each event.

What we showed is that a brief event involving two sensory modalities is sufficient to form a memory trace in 2-year-olds and that learning does not need to be distributed in time to induce retention. In our protocol, the option of maintaining the information in working memory was ruled out by the distractive activities performed by the children during the 30-min delay. Therefore, it can be reasonably assumed that the participants had already started to consolidate the information into more permanent representations. In future work, it would be interesting to investigate whether shorter visual

exposures could yield similar results. Another perspective to our work would be to examine whether and how children generalize this new knowledge to novel instances (e.g., would a single learning experience still enable the shape bias effect during generalization?). Finally, it would also be interesting to examine whether recall could survive longer delays, including overnight, without rehearsal. Although it has been shown that preschoolers are capable of retaining novel pairings ostensively named 1 week after exposure (Gordon & McGregor, 2014), it might be that multiple learning events distributed in time are still required for very long-term retention in 2-year-olds. A recent study demonstrated that 30-month-olds were able to retain the names of objects presented four times each over a week (Wojcik, 2017). Nonetheless, the participants performed an encoding test immediately after learning, which itself induced a rehearsal of the information and thus reinforced the mappings (see Roediger & Butler, 2011, for a review). In another experiment, preschoolers were presented with novel objects casually labeled with pseudowords and demonstrated retention on immediate tests but required additional memory supports (saliency, repetition, and generalization) to retain the associations after a week or month (Vlach & Sandhofer, 2012). Altogether, it is still unclear whether a single learning experience alone is enough for declarative memory to sustain longer delays, especially early in life.

Conclusions

We showed that forming a memory trace for associated cross-modal sensory inputs following a single learning experience is possible in children as young as 2 years. To the best of our knowledge, it is the first evidence for word learning that is not reliant on repetition so early in development. Finally, given the absence of increased performance in 4-year-olds, we propose that the word learning strategies may evolve during development and that ostensive labeling might not be the sole efficient method to induce retention in older children.

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