Did the Popsicle Melt?
Preschoolers' Performance in an Episodic-like Memory Task

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Abstract

Episodic memory has been tested in non-human animals using depletion paradigms that assess recollection for the “what,” “where” and “when” (i.e., how long ago). This paradigm has not been used with human children, yet doing so would provide another means to explore their episodic memory development. Using a depletion paradigm, preschool-aged children were presented in two trials with a preferred food that was only edible after a short interval and a less preferred food that was edible after the short and long intervals. Younger (mean= 40 months) and older (mean=65 months) children tended to choose their preferred food after the short intervals, but did not switch to selecting their less-preferred food after the long intervals. Importantly, their choices did not differ with age. Although older children better remembered “what”, “where” and “what is where” than did younger children, neither age group successfully estimated “how long ago” an event occurred. Finally, both age groups spontaneously recalled information about Trial 1. We also analyzed the relation between the different measures used in the study but no clear patterns emerged. Results are discussed with respect to the cognitive mechanisms necessary to succeed in depletion paradigms and the measurement of episodic memory more broadly.

Keywords: episodic memory, episodic-like memory, children

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Memory is an essential aspect of cognition. The content of our recollections, how this content is accessed and the length of time we remember this content are some of the many features that define different types of memory systems (Miyashita, 2004; Squire, 1992). The episodic/semantic distinction is one of the most influential in memory research because it distinguishes memories based on their content (e.g., what I did during my last holiday) and on how this content is accessed (e.g., awareness) (Tulving, 1972). Tulving (1972) originally defined semantic memory as our database of knowledge about the world, including words, objects, places, people and their inter-relationships. In contrast, episodic memory was defined as memory for "temporally dated episodes or events, and the temporal-spatial relations" among them (Tulving 1972, p. 385). In terms of content, episodic memory was thus described as the *what*, *where* and *when* of a specific event. For example, when we state that Newcastle is in the North of England, we are drawing on semantic memory; however, when I remember walking along the Tyne River with a friend last summer, I am drawing on episodic memory. This distinction originally focused on the different types of information processed by the two systems: unique spatial–temporal contexts for episodic memory and facts and concepts for semantic memory.

More recently, Tulving (1983) has argued that the critical distinction lies less in memory content and more in the type of phenomenological experience associated with the memory. Accordingly, he suggested that autonoetic consciousness is a defining property of episodic memory and is expressed in experiences of mental time travel or, in the mental reconstruction of previous personal experiences at which one was present (see also Suddendorf & Busby, 2005; Suddendorf & Corballis, 2007). Nonetheless, this ability still presupposes that the individual can retrieve the spatial-temporal context in which the to-be-remembered event occurred. As such, spatial-temporal context remains a critical component of episodic memory. In contrast, noetic consciousness is associated with semantic memory and does not require mentally traveling back in time but, rather, an awareness of familiarity or knowing.

Research on episodic memory in human adults has mainly relied on the use of verbal tasks. In these tasks, participants are asked to describe the content of a memory and the subjective experience (i.e., type of awareness) associated with remembering this content (e.g., Buckner & Carroll, 2007; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). The use of verbal approaches for studying the development of episodic memory has shown that even very young children remember past events (e.g., Bauer, 1996; Busby & Suddendorf, 2005; Meltzoff, 1995; Nelson, 1988). For example, 2-year-olds can describe “what” happened to them several months earlier and by the age of 3 begin to talk about events that took place more than 12 months before (e.g., Fivush, 2011; Peterson, 2012 for reviews). Importantly, this research has also demonstrated that young children remember information about the spatial component of past events (e.g., see Bauer, 2007, and Pathman & St. Jacques, 2014, for reviews). For instance, by age 3, children can provide some information about “where” (e.g., a park) a particular event took place when describing personal past events (e.g., Bauer & Larkina, 2014). Recently, Bauer, Stewart, White, and Larkina (2016) showed that 4-year-olds not only succeeded at identifying “where” the events happened but also at binding “what” they did “where.”

As for the temporal aspect, although infants are capable of sequencing actions within a particular event (e.g., Bauer, Wenner, Dropik, & Wewerka, 2000), ordering events on conventional timelines is a more challenging ability that emerges later in development (e.g., Friedman, 2003). In a recent study using such conventional timescales, Pathman, Larkina, Burch, and Bauer (2013) showed that 6- and 8-year-olds, but not 4-year-olds, accurately judged the order of two particular personal past events (see also Pathman, Doydum, & Bauer, 2013, for similar findings). However, these tasks do not necessarily tap into the phenomenological experience associated with the recollection of past events. As such, the use of verbal tasks to investigate the phenomenology of episodic memory (i.e., autonoetic awareness) still poses a challenge for developmental researchers.

Comparative psychologists are faced with similar problems because non-human animals cannot verbalize the subjective experience associated with the recollection of a past event. It is thus challenging to design tasks that successfully distinguish animals’ episodic memories from animals’ semantic memories (though see Clayton & Russell, 2009, for a “ Kantian minimalist” approach in which it is argued that re-experiencing an event can be empirically assessed by using perspective-taking and spatial-orientation paradigms). In an attempt to overcome this limitation, Clayton and Dickinson (1998) developed one of the most influential approaches to test episodic memory in non-human animals: the episodic-like memory depletion paradigm or, the "what-where-when" paradigm. Based on Tulving's original definition of episodic memory (Tulving, 1972), Clayton and Dickinson tested whether scrub-jays could remember *what* type of food they cached, *where* they cached it, and *when* (i.e., how long ago) they cached it. Because the authors acknowledged that their paradigm did not directly assess the phenomenological component of the scrub-jays' memories, they referred to it as an "episodic-like" memory paradigm.

In Clayton and Dickinson's experiment (Clayton & Dickinson, 1998), scrub-jays (*Aphelocoma californica*) cached two types of food: preferred, but perishable, wax worms and less-preferred, but non-perishable, peanuts. When recovering their caches, scrub-jays searched for worms if only a short time had passed, but switched to peanuts if a long time had elapsed since caching. Thus, birds successfully recalled the type of food they had cached (i.e., "what"), its location (i.e., "where"), and how long ago (i.e., "when") they had cached it (Clayton & Dickinson, 1998). Consequently, these results were taken as evidence that scrub-jays had episodic-like memories. Several studies using a similar depletion paradigm have now shown that other birds (Feeney, Roberts, & Sherry, 2009; Zinkivskay, Nazir, & Smulders, 2009), rodents (Babb & Crystal, 2006; Bird, Roberts, Abroms, & Crupi, 2003; Ferkin, Combs, del Barco-Trillo, Pierce, & Franklin, 2007), and great apes (Martin-Ordas, Haun, Colmenares, & Call, 2010) also recall the what-where-when of past events.

However, episodic-like memory tasks differ from episodic memory tasks in three important ways: (1) episodic-like memory tasks do not necessarily assess autonoetic awareness (i.e., conscious recollection)—a defining feature of episodic memory; (2) the "how long ago" component does not necessarily test *chronosthesia* or, "…individuals' awareness of the temporal dimension of their own and others' existence…" (Tulving, 2002, p. 313), which Tulving argued was critical to episodic memory; and, (3) episodic memories are usually encoded in a single trial, whereas episodic-like memory tasks require training and thus involve more than one exposure to the event. Together, these factors have led some authors to argue that episodic-like memory tasks might rely on semantic, rather than episodic, memory (e.g., Suddendorf & Busby, 2005; Suddendorf & Corballis, 1997; Suddendorf & Corballis, 2007).

Until recently, however, depletion paradigms had not been used with humans (either adults or children). This is surprising given that data on this task with children, especially, may shed light on the extent to which episodic memory is needed to succeed. More specifically, if passing a what-where-when depletion task relies on episodic memory, then older children should outperform younger children given previous findings that show substantial improvement in children's recollection skills between 3 and 5 years of age (e.g., Busby & Suddendorf, 2005; Clayton & Russell, 2009; Quon & Atance, 2010). In contrast, if succeeding on this paradigm largely relies on semantic memory (or other "non-episodic" processes), then children as young as 3 should pass and age differences should be less likely. This is because even 3-year-olds show well-developed semantic memory abilities (e.g., Hudson, 1990; Nelson, 1988). In fact, a recent study showed that 3-year-olds performed as well as 4-year-olds in a problem-solving situation in which only semantic memory was required to succeed (Martin-Ordas, Atance & Call, 2014).

Interestingly, two recent studies showed that human adults and children as young as 3 recalled what, where, and when something happened (Hayne & Imuta, 2011; Holland & Smulders, 2011). In these studies, participants were asked to recall in which room (i.e., "where") and in which order (i.e., "when") toys (Hayne & Imuta, 2011) or coins (Holland & Smulders, 2011) (i.e., "what") were hidden. There are two important differences, however, between these two studies and Clayton and Dickinson's (1998) depletion paradigm. First, the definition of the "when" component is not the same across studies. In the studies with human children and adults, the "when" component is defined as the "order" in which the hiding events took place, whereas in the studies with the scrub-jays, it is defined as "how long ago" a past event took place (hereafter, we thus refer to the paradigm developed by Clayton and Dickinson as "what-where-how long ago"). Second, the behavioral criteria used to assess episodic memory also differ across both sets of studies. Clayton and Dickinson (1998) assessed scrub jays' episodic memories by measuring their correct choices (i.e., choosing worms after the short retention interval and peanuts after the long retention interval). In contrast, adults' and children's episodic memories were measured by their responses to the "what" (e.g., coins), "where" (e.g., in which room) and "when" (e.g., order in which the coins were hidden) questions. As such, we do not know whether children would pass a what-where-*how long ago* task because the "when" component has been assessed differently in the animal and human research.

To address this issue, we combined the methods used by Clayton and Dickinson (1998) with those recently used with humans (Hayne & Imuta, 2011;

Holland & Smulders, 2011) to determine whether pre-school children not only encode information about “what” was hidden “where”, but also “how long ago.” Our task entailed the experimenter hiding food in two of three locations on a platform. One location contained a favourite but perishable food (grape popsicle) and the other a less-preferred but non-perishable food (box of raisins). The third location remained empty. Children were asked to choose from one of the three locations (i.e., children were told that they could have what was under their chosen box) after a 3-min or 1-hour retention interval (RI) and to answer different memory questions about “what” we hid, “where” we hid it, and “how long ago” we hid it. After 3 minutes, the popsicle was still edible, whereas after 1 hour it was not (i.e., it had melted and become inedible).

As mentioned earlier, subjects’ choice (e.g., worms or peanuts) after the RIs is the dependent variable used to assess episodic-like memory in non-human animals whereas, with humans, verbal responses to the “memory check” questions (i.e., “what,” “where,” and “in which order”) are the commonly used dependent variables. Although Hayne and Imuta (2011) also used a behavioural measure to assess whether children remembered “*where”* (i.e., children had to find the toys hidden in the rooms) and “*in which order”* (e.g., children were asked to enter the rooms in the order in which they experienced them before) the toys were hidden, the “what” component of children’s memories could not be assessed behaviourally. Importantly, there was no measure of whether or not children can use duration to inform their item choices (e.g., choose the preferred food after a short interval and the less preferred food after a long interval) - this being a key dependent measure in the animal literature and one that we also wished to assess. In sum, our paradigm allowed us to obtain both dependent variables; that is, participants’ choices after the RIs and their verbal responses to the memory check questions. As noted earlier, because research has shown that episodic memory shows important developments between ages 3 and 5 we predicted that older children would perform better than younger children in our what-where-how long ago task.

Our study also entailed two experimental trials. Trial 1 allowed us to determine how children performed when they were unaware of what the task would involve [or, the element of “surprise” (Zentall, Clement, Bhatt, & Allen, 2001)]. We wanted to capture this notion of surprise because it has been argued that a crucial feature of episodic memory is that retrieval can occur when encoding is incidental and memory assessment is unexpected (Singer & Zentall, 2007; Zentall, Singer, & Stagner, 2008; Zentall et al., 2001; Zhou & Crystal, 2011). Trial 2 thus allowed us to assess the effect of previous experience on participants' performance, with the prediction that those children who received the 1-hour RI in Trial 1 (i.e., experienced the melted popsicle) should perform better on the 1-hour RI in Trial 2 than those children who received the 3-min RI in Trial 1. Similarly, if experiencing the "what", "where" and "how long ago" questions in Trial 1 facilitates subsequent encoding of this information then children should perform better on these questions in Trial 2, as compared to Trial 1.

Because Trial 2 took place in the exact same context as Trial 1, this created a situation in which *direct retrieval* (Conway, 2005) could be tested. Research with human adults has shown that memories of personal past events (i.e., episodic memory) can either be retrieved through an effortful process that involves strategically searching for a particular episodic memory—so called *generative* retrieval- or can be triggered effortlessly and spontaneously by internal (e.g., hunger) or external (e.g., a room) cues —or, so called *direct* retrieval (Conway, 2005; Conway & Pleydell-Pearce, 2000). In contrast to generative retrieval, direct retrieval—also referred to as cue-dependent retrieval- is argued to emerge earlier in development because it requires less executive control (Berntsen, 2009; Raby & Clayton, 2009). Previous research has shown that it is only relatively late in development that children start to use retrieval strategies (Brown, Bransford, Ferrara, & Campione, 1983; Schneider & Bjorklund, 1998) and thus younger children are reported to benefit from being provided with external cues (Gee & Pipe, 1995). For example, Gordon and Follmer (1994) asked 3-, 5- and 7-year-olds to remember details about a doctor's check-up. Those children who were tested in a room that resembled the one where the actual check-up took place recalled more information and more details about this past event than those children who were assessed with a regular verbal protocol. This was especially true of the 3-year olds. Due to the high degree of cue overlap between our two trials, we were curious about whether even 3-year-olds (during their second visit to the laboratory) might spontaneously retrieve memories about their personal past experiences in Trial 1.

In sum, we expected older children to outperform younger children both at making the correct choices (i.e., choosing the popsicle after a short RI and the raisins after a long RI) in our depletion paradigm and responding correctly to the memory check questions (i.e., “what,” “where,” and “how long ago”). We also expected all children to perform better in the second trial compared to the first - both in terms of correct choices and responses to the memory check questions. Moreover, participants’ correct choices in Trial 2 should be influenced by the type of trial they received first. As for spontaneous recall, given that cue overlap between encoding and retrieval facilitates direct retrieval—and this is particularly true for younger children— we expected that during the second trial both younger and older children would retrieve memories of the previous event (i.e., Trial 1). This would suggest that when presented with appropriate cues (e.g., rooms where children were tested in Trial 1) even younger children *spontaneously* remember past events. Finally, if our three measures (i.e., correct choices, responses to the memory check questions, and direct retrieval/spontaneous recall in Trial 2) reflect the same memory abilities (i.e., episodic memory), then performances on them should be related. Examining this relation is a particularly novel contribution of our methodology given that no studies have addressed whether these different episodic memory measures tap similar processes in young children.

Methods

Participants

Of the 84 typically-developing children who were recruited, 36 were excluded because they preferred raisins to popsicles, disliked raisins, or failed to attend both sessions (i.e., Trials 1 and 2). Our final sample included 48 children (27 females; 21 males, M=51 months) divided into younger (M=40 months, range=36 to 52 months, n=24) and older (M=65 months, range=58 to 71, n=24) age groups to allow us to test our developmental predictions. All participants were predominantly White, middle class, and fluent in English. Our experiment received ethical approval from the Office of Research Ethics and Integrity at the University of Ottawa. Parents provided written informed consent for their children’s participation and children also provided their verbal assent.

Materials and Procedure

The apparatus consisted of three distinct cardboard boxes (approximately 12 cm wide x 19 cm long x 8.8 cm high each) and a wooden platform (91 cm long x 75.5 cm wide) in which three holes (5 cm diameter) were drilled and then covered with a plastic netting (see Figure 1). The netting allowed liquid (from the melting popsicle) to pass through and collect inside a cup that was hidden under the platform. Experimenter (E) and participant sat facing each other. E placed the three boxes on the platform about 20 cm apart, showed the participant two food rewards, and then placed them under two of the three boxes. The experiment took place in two rooms: Room 1 and Room 2. The hiding event took place in Room 1 and then participants waited 3 min or 1 hour, depending on trial type, in Room 2.

Figure 1

Each of the two trials consisted of five main events: (1) food preference test, (2) hiding event, (3) critical choice question, (4) memory check questions and, (5) "how long ago" question. In addition, for Trial 2 only, children's direct/spontaneous recall was assessed.

1. Food preference test. The box of raisins (4.6 cm long x 3.4 cm wide x 1.7 cm high) and the popsicle (3 cm long x 2.5 cm wide x 1.5 cm high) were placed on two small dishes and children were asked "*Which one of these two snacks do you like best: popsicles or raisins*?" At this point in the procedure, participants did not receive either food item. The preference test was then followed by the hiding event.

2. Hiding event. For each of the two snacks E said: "*Look what I have here! I am going to put it here*". E then placed the popsicle in one location, the raisins in another, while the third box remained empty. This empty box allowed us to control for children at least remembering which boxes had food under them[1]. Children received either a 3-min trial or a 1-hour trial. The 3-min and 1-hour designations refer to the length of time that elapsed between hiding the food items and allowing participants to choose one of the boxes (i.e., critical choice). On the 3-min trials, the popsicle and raisins were both available (i.e., edible), whereas on the 1-hour trial the popsicle melted and only the raisins were edible. During the RIs, children went to Room 2 and

[1] Note that only 2 older children chose the empty box in Trial 1—one of them in the 1-hour trial and the other one in the 3-min trial- and 1 younger child did so in Trial 2 (1-hour trial).

participated in a series of unrelated activities with E. Importantly, before leaving Room 1, E clearly stated "*the door is going to be locked so no one can go inside the room while we are not there*".

3. Critical choice question. After the 3-min or 1-hour RI, E and participant returned to Room 1 and E asked the child the critical choice question, "*Now you can have what is inside one of these boxes. Which one are you going to choose*?" This question is akin to scrub jays, for example, being allowed to retrieve a particular food (e.g., peanuts or wax worms) after a specified RI. In the 1-hour trials, after the box was uncovered and children had been asked the *memory check questions* (see below), E asked participants "*What happened to the popsicle*?" The majority of children stated that the popsicle had melted thus suggesting that they understood the melting process. Nonetheless, for all children, E explained or confirmed that the popsicle had indeed melted.

4. Memory check questions. Children were also asked three memory-check questions to assess whether they remembered "what" ("*Do you remember what I put under the boxes*?"), "where" ("*Do you remember which boxes have something under them*?") and "what is where" ("*Do you remember where the popsicle is*? *Do you remember where the raisins are*?"). These questions are similar to those asked in the studies with adults and children described earlier in our Introduction. Note, that half of the participants were asked the critical choice question first and the memory-check questions second, whereas for the other half this order was reversed. Importantly, the order in which we asked these questions did not significantly affect younger children's performance (Trial 1: χ^2= 2.59, *df*=1, *p*=.21; Trial 2: χ^2=2.24, df=1, *p*=.21) or older children's performance (Trial 1: χ^2= 2.25, *df*=1, *p*=.21; Trial 2: χ^2= 1.73, df=1, *p*=.24). Once participants indicated the location/box they wanted to uncover and answered the memory check questions, E lifted the chosen box to allow them to have what was inside.

5. How long ago question. This question was always asked at the end of the trial and was worded as follows: "*Do you remember when we were in the other room (i.e., Room 2)? Did it feel like the time that it takes to brush your teeth, or like the time that it takes your Mom to make dinner and then eat dinner all together?*" E pointed to two pictures while presenting these two different options: one depicted a small child brushing her teeth and the other depicted a woman cooking with her family having dinner in the background. In addition, two lines were drawn under each of the two pictures: a short line for "brushing teeth," and a longer line for "making and eating dinner." The "how long ago" question was a novel feature of our paradigm and allowed us to determine whether children's incorrect responses on the critical choice question (e.g., choosing the popsicle after a 1-hour RI) was due to difficulties estimating the amount of time/duration that had elapsed between the hiding and retrieval events.

Children received two trials separated by five to seven days. Half received the 3-min trial followed by either the 3-min trial or 1-hour trial. The other half received the 1-hour trial followed by either the 3-min or 1-hour trial resulting in 4 experimental conditions, with equal numbers of older and younger children in each: 1-hour (first) trial and 1-hour (second) trial; 1-hour trial and 3-min trial; 3-min trial and 3-min trial; 3-min trial and 1-hour trial. This combination of conditions allowed us to address whether (or not) experiencing the melted popsicle in Trial 1 significantly improved performance in Trial 2. Children were randomly assigned to each of the conditions until the required number of children in each condition was met. Hiding locations and box locations were counterbalanced within and across participants.

Scoring and Analyses

Trials were video-recorded and participants' choices were scored as a function of which box they pointed to first (correct box=1; incorrect box=0).

Critical Choice Question. In keeping with previous literature using depletion paradigms, choosing the box hiding the popsicle in the 3-min trials was considered "correct" because it is the preferred food and is still edible, whereas choosing the empty box or the box with raisins were considered "incorrect". In contrast, in the 1-hour trials, choosing the box hiding the raisins was considered "correct," whereas choosing the empty box or the box hiding the popsicle (which was no longer edible) were considered "incorrect."

Memory-check Questions ("What", "Where", "What is Where"). Participants received a score of 1 for the "what" question (i.e., "*Do you remember what I put under the boxes*?") if they responded with both "*popsicle*" and "*raisins*." Any other response was scored as 0. Participants received a score of 1 for the "where" question (i.e., "*Do you remember which boxes have something under them*?") if they pointed at the two boxes that contained the food items. Any other response was scored as 0. For the "what is where" question (i.e., "*Do you remember where the popsicle is*? *Do you* *remember where the raisins are*?"), participants received a score of 1 if they pointed at the box containing the popsicle and at the box containing the raisins. Any other response was scored as 0.

"How Long Ago" Question. For the "how long ago" question (i.e., "*Do you remember when we were in the other room?: Did it feel like the time that it takes to brush your teeth or like the time that it takes your Mom to make dinner and then eat dinner all together?*"), participants received a score of 1 if they answered "*brushing teeth*" after the 3-min trial and "*making and eating dinner*" after the 1-hour trial.

Direct/Spontaneous Recall. For the second trial only, we coded children's spontaneous utterances about the events that took place during Trial 1. Utterances were either classified as being "central" (e.g., remembering that the popsicle melted), or "peripheral" (e.g., remembering the door being locked) to the past event. Note that E never prompted these memories. We calculated four scores: overall/total spontaneous recollection (i.e., total number of central memories + total number of peripheral memories), total number of central memories, total number of peripheral memories, and a categorical score that reflected whether children spontaneously recalled information or not (i.e., either central features or peripheral features) about Trial 1 (recall=1, no recall=0). We began coding children's utterances as soon as children entered Room 1 at the beginning of Trial 2 and ended our coding immediately prior to E asking the test questions (i.e., critical choice question and memory-check questions in Room 1).

Reliability Analyses. A second coder blind to the hypotheses coded 23% of the trials. Reliability was 100% for the *critical choice* question, *memory-check* questions, and *how long ago* question. Kappa was also fairly high (.74) for the spontaneous recall measure. All disagreements were resolved through discussion and the scoring criteria revised. These revised criteria were then used to score the remaining 77% of the data.

Analyses. We used Pearson chi-square tests to analyze children's performance in the critical choice question in Trial 1, their performance in the critical choice question in Trial 2 as a function of what type of trial they received first, and the effect of age. We used binomial tests to assess whether children were above chance in the critical choice question (chance=33%). We used Mann-Whitney tests to analyze the effects of age on spontaneous recall and to analyze the effect of Trial 1 (i.e., 3 min or 1 hour RI) on spontaneous recall. Wilcoxon tests were used to analyze which features of the event (central or peripheral) children remembered most. Finally, we used the contingency coefficient to analyze the relation between children's performance on the critical choice question and memory-check questions in each trial. For Trial 2, we also calculated the contingency coefficient for children's performance on the critical choice question and direct/spontaneous retrieval (hereafter referred to as "spontaneous recall") and the memory-check questions and spontaneous recall. All statistical tests were exact two-tailed and results were considered significant if $p<.05$.

Results

Critical Choice Question

Performance in Trial 1. Recall that participants were either given a 3-min RI or a 1-hour RI in Trial 1. Whereas choosing the box containing the "popsicle" is the correct choice in the 3-min RI, the box hiding the "raisins" is the correct choice in the 1-hour RI. There were no differences in performance between the younger children and older children in either the 3-min RI ($\chi^2= 3.55$, $df=1$, $p=.155$), or the 1-hour RI ($\chi^2= .253$, $df=1$, $p=1$). More specifically, both younger and older children tended to correctly choose the box hiding the popsicle in the 3-min RI (91 % of younger children *vs.* 60% of older children) and *incorrectly* choose it in the 1-hour RI (84% of younger children *vs.* 75% of older children). Because age did not significantly affect children's responses to the critical choice question, we collapsed the data to conduct chance analyses for both the 3-min and 1-hour RIs. Binomial tests revealed that whereas children chose the box hiding the popsicle significantly above chance after 3 min ($p<.001$), they did not choose the box hiding the raisins significantly above chance after 1 hour ($p=.292$). Rather, 83 % of the children chose the box hiding the popsicle, which is more often than expected by chance ($p<.001$).

Performance in Trial 2 as a Function of Trial 1. To investigate the effect of previous experience on children's responses, we analyzed performance in Trial 2 as a function of the trial children received first (Figure 2). These analyses were run separately for younger and older children. For the younger children, performance in the second 1-hour trial was not superior for those children who received the 1-hour trial first as compared to those who received the 3-min trial first ($\chi^2= .000$, $df=1$, $p=1$). Similarly, performance in the second 3-min trial was not affected by whether children received a 3-min or 1-hour RI in Trial 1 ($\chi^2= .000$, $df=1$, $p=1$). As was the case with younger children, having received the 1-hour RI or 3-min RI in the first trial did not affect older children's performance in the second 1-hour trial (χ^2= .000, *df*=1, *p*=1) or in the second 3-min trial (χ^2= 6.00, *df*=1, *p*=.061). Together these results show that children's choices in Trial 2 were not significantly affected by their experience in Trial 1. Especially surprising in this respect was that experiencing the melted popsicle in Trial 1 (i.e., 1-hour RI) did not lead children to make significantly more correct choices after experiencing this same RI in Trial 2 (this, as compared to children who received the 3-min RI in Trial 1).

Collapsing across age groups to compare children's performance to chance levels yielded the following results: Children correctly chose the box hiding the popsicle significantly above chance in Trial 2 of the 3 min-3 min condition (*p*=.008) but, unexpectedly, not in Trial 2 of the 1 hour-3 min condition (*p*=.718). Importantly, however, children did not correctly choose the box hiding the raisins significantly above chance in either Trial 2 of the 3 min-1 hour condition (*p*=.806) or Trial 2 of the 1 hour-1 hour condition (*p*=.806) (Figure 2). Instead, children in both of these conditions chose the popsicle significantly above chance (*p*=.016 and *p*=.008, respectively).

Children's failure to correctly choose the popsicle in Trial 2 of the 1 hour-3 min condition suggests that children who experienced the melted popsicle in Trial 1 (i.e., 1-hour RI) may then have avoided choosing the box hiding the popsicle after the 3-min RI in Trial 2. However, it is then surprising that children who received the 1 hour-1 hour condition did not do the same. Instead, as noted above, children were significantly above chance in choosing the box hiding the popsicle after the 1-hour RI in Trial 2. Moreover, 73% of those children who first received the 3-min RI in Trial 1 continued to choose the popsicle after the 1-hour RI in Trial 2 (*p*=.016) and those children who received the 3min-3min condition continued to choose the popsicle in Trial 2, with only 25% of them choosing the box containing the raisins (*p*=.806). We will return to this issue in the Discussion.

Figure 2

Memory-check Questions ("What", "Where", "What Is Where")

Recall that children were asked a series of questions assessing “what” (i.e., “*Do you remember what I put under the boxes*?”), “where” (i.e., “*Do you remember which boxes have something under them*?”), and “what is where” (i.e., “*Do you remember where the popsicle is*? *Do you remember where the raisins are*?”). Our next set of analyses addressed whether younger and older children differed in the extent to which they remembered these various pieces of information.

Performance in Trial 1. Older children better remembered “what” (χ^2= 6.00, *df*=1, *p*=.030; 50 % of younger children *vs.* 83% of older children) and “what is where” (χ^2= 6.70, *df*=1, *p*=.023; 66% of younger children *vs.* 95% of older children) than younger children. In contrast, there were no significant differences on the “where” question (χ^2= 3.63, *df*=1, *p*=.111; 58% of younger children *vs.* 83% of older children).

Performance in Trial 2. As compared to younger children, older children better remembered “what is where” (χ^2= 8.08, *df*=1, *p*=.010; 62% of younger children *vs.* 95% of older children), but not “what” (χ^2= 0.35, *df*=1, *p*=1; 91% of younger children *vs.* 95% of older children), or “where” (χ^2= 4.54, *df*=1, *p*=.072; 66% of younger children *vs.* 91% of older children).

How Long Ago Question

Recall that children were asked a final question (i.e., “*Do you remember when we were in the other room? Did it feel like the time that it takes to brush your teeth, or like the time that it takes your Mom to make dinner and then eat dinner all together?*”) to assess their estimation of the amount of time that had passed between the hiding and retrieval events. Interestingly, there were no significant age differences on this question on either Trial 1 (χ^2= 2.37, *df*=1, *p*=.212; 54% of younger children *vs.* 75% of older children), or Trial 2 (χ^2= .000, *df*=1, *p*=1; 76% of younger children *vs.* 75% of older children). In fact, older children were only above chance in estimating the correct duration of the second 3-min trial (Binomial test *p*<.05). For all other trials, both younger and older children’s performance was not significantly different from chance.

Spontaneous Recall During Trial 2

Thirty (65%) of the 46[2] children spontaneously recalled features of the event they experienced the week before (*mean*=1.32, *SEM*=.18, *n*=46). Moreover, we found

[2] Videos of the second session were unavailable for two of the children and so coding of their spontaneous recall was not possible.

no differences in spontaneous recall between younger and older children (Mann-Whitney test: *U*=206, *p*=.18, $n_{younger}$=23, n_{older}=23; younger children: *mean*=1.00, *SEM*=.25, *n*= 23; older children: *mean*=1.56, *SEM*=.27, *n*=23). Children tended to spontaneously recall more information when they had experienced the 1-hour trial (and therefore the popsicle melting) than when they had experienced the 3-min trial (Mann-Whitney test: *U*=183.5, *p*=.06, n_{3min}=22, n_{1h}=24; 3 min: *mean*=1.00, *SEM*=.27, *n*= 22; 1 hour: *mean*=1.62, *SEM*=.25, *n*=24) the week before. Although we did not find significant differences between the number of central (e.g., popsicle melting) and peripheral (e.g., locking the door) features that children retrieved about the event (Wilcoxon test: *T*=13.19, *p*=.58, *n*=27), children tended to spontaneously recall more central features when they had experienced the 1-hour trial the week before than when they had experienced the 3-min trial (Mann-Whitney test: *U*=190, *p*=.07, n_{3min}=22, n_{1h}=24) the week before. No differences in recall of the peripheral features of the event were found (Mann-Whitney test: *U*=220, *p*=.29, n_{3min}=22, n_{1h}=24).

Relation between the Critical Choice Question, the Memory-check and "How Long Ago" Questions, and Spontaneous Recall

Performance in Trial 1. Performance in the critical choice question was not significantly related to remembering "what" (*C*=.029, *p*=1, *n*=48), "where" (*C*=.065, *p*=.756, *n*=48), "how long ago" (*C*=.017, *p*=.912, *n*=45) or to the ability to bind "what is where" (*C*=.139, *p*=.466, *n*=48).

Performance in Trial 2. Similar to Trial 1, correctly responding to the critical choice question was not significantly related to remembering "what" (*C*=.213, *p*=.131, *n*=48), "where" (*C*=.086, *p*=.548, *n*=48), "what is where" (*C*=.187, *p*=.186, *n*=48) or to the ability to spontaneously recall events from the week before (*C*=.248, *p*=.082, *n*=46). However, we did find that performance in the critical choice question was significantly related to correctly answering the "how long ago" question (*C*=.281, *p*=.043, *n*=48).

Next, we analyzed the relation between remembering what-where-how long ago and spontaneous recall. We found that remembering "what" (*C*=.213, *p*=.131, *n*=48) and "where" (*C*=.213, *p*=.131, *n*=48) were not significantly related to spontaneous recall. However, recalling "what is where" was marginally related to spontaneous recall (*C*=.269, *p*=.058, *n*=46), and "how long ago" was positively related to spontaneously retrieving what happened a week earlier (*C*=.313, *p*=.025, *n*=46).

Discussion

This is the first study to adapt a what-where-how long ago depletion paradigm used with non-human animals for preschool children. Our results showed that 3- to 5-year-olds tended to correctly choose the preferred and perishable food (i.e., popsicle) after the short RI but failed to reverse their choice and choose the less preferred and non-perishable food (i.e., raisins) after the long RI. Rather, children tended to choose the popsicle, regardless of the duration of the RI. Moreover, experiencing the melted popsicle in the first trial did not improve children's performance in the second trial. We also tested the extent to which children remembered information about the "what," "where," and "what is where" of the past events or, the "memory-check" questions. Here, we found that older children tended to more accurately remember this information than did younger children (though the younger children's responses tended to improve in Trial 2). We also found that both younger and older children had difficulties estimating the duration (i.e., "how long ago" question) of the trials and their performance in this respect did not improve in Trial 2.

Spontaneous recall (i.e., amount of information remembered about Trial 1) also did not differ in younger and older children, though the salience of the event (i.e., popsicle melting in the 1-hour trial) experienced the week before tended to affect recall. Finally, we analyzed the relation between the critical choice question, memory-check and "how long ago" questions, and spontaneous recall and found that children's responses to the critical choice question (i.e., choosing which of the three boxes to open) were only related to children's ability to remember "how long ago" in Trial 2. In addition, the ability to spontaneously retrieve what happened a week earlier was related to retrieving "what is where" and "how long ago" in Trial 2.

Critical Choice Questions

Older children did not outperform younger children on the critical choice questions. When collapsing across age, children correctly chose the popsicle on the majority of the 3-min trials, but failed to correctly choose raisins on all of the 1-hour trials. As such, these findings differ from research showing that non-human animals (e.g., Clayton & Dickinson, 1998; Martin-Ordas et al., 2010) take into account the length of the RI when making their choices (i.e., preferred food after short intervals, less preferred food after long intervals). Because children as young as 3 have an understanding of the transformation of certain substances (e.g., ice melts with time)

(Gelman, Bullock, & Meck, 1980), it seems unlikely that children in our study answered the critical choice question incorrectly in the 1-hour RIs because they lacked the "semantic knowledge" that "popsicles melt." Moreover, even if this lack of knowledge accounted for their poor performance in Trial 1, children should have acquired this knowledge by Trial 2. Yet, children in the 1 hour-1 hour condition performed no better than children in the 3 min-1 hour condition. This is surprising given that the goal of depletion paradigms like ours is to measure episodic-like memory and, as such, older children would be expected to succeed.

However, it may be that children's choices on depletion paradigms is subject to a decision-making process in which factors such as which reward children prefer, or which reward children obtained the week before, play a more fundamental role than episodic memory, per se. For example, children may have conceived the food preference test as the critical choice question and once they decided what they "liked best" they maintained their choice independently of the RI. Moreover, their food preference and critical choice in the second trial may have been influenced by the food reward they obtained in Trial 1. For example, those children who chose the popsicle in the first 1-hour trial may have decided to choose the popsicle in Trial 2 because they had not obtained it the first time. Alternatively, those children who chose the popsicle in the first 3-min trial may have decided to choose the raisins in Trial 2 because they desired something different. These and other hypotheses could be tested using an experimental design in which children are provided with the popsicle or raisins in Trial 1, independently of the duration of the trial. This is an important future direction that would help determine the extent to which depletion paradigms used with non-human animals can be adapted for young children. This approach would also help to gain better traction on the different types of motivational factors that may be operative in children but not in animals, and vice versa, in depletion paradigms.

Memory-check Questions and "How Long Ago" Question

Similar to the results reported by Hayne and Imuta (2011, see also Bauer et al., 2016), we found that, overall, older children were better at recalling "what", "where" and "what is where" than younger children. Accordingly, difficulties encoding this specific information cannot likely account for why older children, at least, did not pass our critical choice question. In contrast, both age groups failed to estimate how much time had elapsed between the baiting/hiding event and the point in time when they were asked to choose which box to uncover (i.e., “how long ago” question). Thus, failing to estimate the duration of the trial might have diminished children’s performance in the critical choice question. Although Hayne and Imuta (2011) found that 4-year-olds were successful on the “when” question, “when,” in this case, was defined as “in which occasion” [e.g., order of events (Hayne & Imuta, 2011; Holland & Smulders, 2011; Eichenbaum, Fortin, Ergorul, Wright, & Agster, 2005)]. It is also important to note that it is not until later in development that children can sequence past events using timescales (e.g., Pathman et al., 2013a; Pathman et al. 2013b). In this regard, our study differs from previous developmental research because we closely mirrored the animal research and defined “when” as sensitivity to “how long ago” the caching/baiting event took place (Clayton & Dickinson, 1998). As such, it is possible that remembering *how long ago* something happened involves different underlying mechanisms (and ones that may be later-developing) than remembering *the order* in which certain events happened. This, too, is an intriguing direction for future research given that there exists very little work on how young children’s estimations of duration are related to other temporal dimensions such as order.

With respect to the encoding of duration or, “how long ago,” specifically, it may be that it is impacted by such factors as the amount of time that elapses between one event and another, as well as event distinctiveness. For example, Friedman and his colleagues (Friedman, 1991; Friedman, Gardner & Zubin, 1995) showed that 4- and 5-year-olds can accurately estimate how long ago two previously experienced events took place when the time between the two events being compared was several weeks. In addition, using a spatial metaphor (i.e., ruler or arrows), children as young as 4 years of age can indicate how long ago yearly events (e.g. Christmas day) took place (Friedman, 2002; Friedman, 2003), as well as events that happened 24 hours, one year, or several years ago (Busby Grant & Suddendorf, 2009). This research suggests at least two reasons for why children in our study had difficulty estimating the duration of the trials: (1) event salience and, more specifically, hiding snacks is likely not as memorable an event as Christmas day, for example; and (2) length of time (e.g., 1 hour, in the case of our study, vs. 1 year, in the case of Busby Grant and Suddendorf, 2009). Either way, our paradigm highlights the fact that estimating duration and, more specifically, using this information to make a correct choice in a depletion paradigm is challenging for preschool children. More broadly, this finding forces us to consider whether estimating duration (at least as assessed in a depletion paradigm) should be considered an integral feature of episodic memory (cf., McCormack, 2001).

The Element of "Surprise" (i.e., Trial 1) and Learning from Experience (i.e., Trial 2)

Comparative psychologists have argued that deliberate encoding (e.g., use of training phases) helps organisms develop expectations of future rewards, thus favoring the storing of this information as semantic rather than episodic memories (Martin-Ordas, Berntsen, & Call, 2013; Martin-Ordas et al., 2014; Zentall et al., 2008; Zentall, Clement, Bhatt, & Allen, 2001; Zhou, Hohmann, & Crystal, 2012). In other words, the memory processes involved in a first encounter/trial of an event may differ from those involved in subsequent trials. For this reason, we were curious about whether children's performance in Trial 1 would differ from their performance in Trial 2 and, moreover, whether the RI (i.e., 3 min or 1 hour) children experienced in Trial 1 would influence their responses in Trial 2. For example, if children in the 1 hour–1 hour condition made use of the information they learned in Trial 1 (i.e., popsicles melt after a long duration), they should perform better in Trial 2.

As mentioned previously, children's experience in Trial 1 did not affect their performance on the critical choice question in Trial 2. In contrast, we found some evidence that younger children's performance on the memory-check questions improved between Trials 1 and 2 (note, that older children's responses were already quite accurate in Trial 1). More specifically, younger children performed worse than older children at remembering "what" and "what is where" in Trial 1. Yet, in Trial 2, only a difference on the "what is where" question remained (and younger children's performance on the "what" question in Trial 2 was significantly higher than in Trial 1, McNemar chi-square: p=0.002) Because the "what" (i.e., popsicle and raisins) is the only component that is constant across trials (the locations where we hid the food items changed across trials), younger children might have expected that we would ask them about the popsicle and raisins in Trial 2 and thus encoded this information in semantic rather than episodic memory. In contrast, remembering "what is where" might have tapped into children's capacity to bind the food items to particular locations and, by age 5, children have developed the capacity to do so. This is interesting in light of arguments that binding contextual features, which facilitates event differentiation, is a critical aspect of episodic memory (Eichenbaum et al., 2005; Newcombe, Lloyd, & Ratliff, 2007).

Spontaneous Recall

Newcombe, Balcomb, Ferrara, Hansen, and Koski (2014) showed that providing 2-year-olds with a cue (e.g., part of the toy they had to find) improved their recall. Consequently, presenting children with the physical environment (e.g., room, objects)—and not only a single cue—in which they actually experienced the encoding event should further help to make memories accessible (Ornstein, 1995; Salmon, 2001; Pipe, Salmon, & Priestley, 2002). And, indeed, our results on spontaneous recall indicate that even younger children were able to remember features of the event that took place the week before. Although not statistically significant, we found a trend for the effect that event salience had on children's recollections. More specifically, children spontaneously tended to remember more information from the 1-hour trials (e.g., melted popsicle) as compared to the 3-min trials (e.g., popsicle did not melt). Interestingly, we did not find that older children remembered more information than younger children. As mentioned in the Introduction, one possibility for this lack of age difference is that direct retrieval requires less executive control—which develops substantially between ages 3 and 5 (Zelazo, Muller, Frye, & Marcovitch, 2003)– than generative retrieval. Accordingly, younger children's access to the memory trace may have been facilitated by the number of cues with which we presented them. In fact, previous research has shown that providing children as young as 3 years of age with real props improves their recall after long delays (i.e., a week) relative to other conditions in which they are asked to verbally report a past event (Gee & Pipe, 1995; Gordon & Follmer, 1994).

Relation between our Measures

Each of the measures used in our study (i.e., critical choice question, memory-check and how long ago questions, and spontaneous recall) arguably tap some aspect of children's episodic memory, yet showed different age-related patterns and not all of them were consistently related. For example, younger children were less successful than older children at remembering some of the individual elements of the what-where-how long ago questions and at integrating the information of "what is where." However, they were just as successful as older children at spontaneously recalling information about Trial 1. Although one could argue that spontaneously recalling vs. not recalling information does not as readily map onto the labels "correct" vs. "incorrect" in the same way as the critical choice or memory check questions do, for example, it is nonetheless important to note that what children remembered was accurate. That is, in no instance did a child report something that was completely unrelated to the events that transpired the previous week.

Interestingly, some components of these three measures were related—although only in Trial 2. For instance, we found that the abilities to remember "what is where" and "how long ago" relate to the ability to spontaneously retrieve information about Trial 1 suggesting that these measures might tap the same memory abilities. Likewise, recalling "how long ago" the baiting event took place was related to performance in the critical choice question. This finding suggests that those children who correctly estimated the duration of the RI were also the ones who correctly answered the critical choice question and, conversely, those children who failed to estimate the duration of the RI also failed the critical choice question. What is compelling about this finding is that this effect was only true for Trial 2 and, consequently, once children *knew* what the task entailed. Thus, one could argue that children do not spontaneously incorporate the duration of the trial into their decisions.

It is important to note that, despite these results, most of the measures used in our study were not significantly related and, as such, it is difficult to argue that they reflect the same memory abilities. Indeed, consistent with our findings, two recent studies – one with adults (Cheke & Clayton, 2013) and one with children (Cheke & Clayton, 2015)- also largely failed to find significant correlations between different measures of episodic memory. Thus, the issue of why various tasks that purportedly measure "episodic memory" are not related clearly merits further empirical attention.

Conclusion

Our episodic-like memory depletion paradigm showed that younger and older preschoolers alike failed to take into account retention interval when deciding whether to choose a non-perishable or perishable food. Consistent with previous findings, however, our results showed age-related changes in children's ability to remember "what" we hid, "where" we hid it, and "what items were hidden where." Our findings also show that, when provided with the appropriate cues, even younger children spontaneously remember information about what happened a week earlier. Finally, we found that both age groups in our study had difficulty estimating the duration of the trials – a potential explanation for why they failed to make the correct critical choice in the depletion paradigm.

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Figure captions:

Figure 1. Apparatus used in the what-where-how long task. The photo depicts (a) the three cardboard boxes and the wooden platform and (b) a detail of one of three holes and plastic netting

Figure 2. Percentage of younger and older children who chose the box hiding the popsicle, the box hiding the raisins or the empty box in the critical choice question grouped as a function of RI and trial type