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# Preschool children's proto-episodic memory assessed by deferred imitation

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In two experiments, both employing deferred imitation, we studied the developmental origins of episodic memory in two- to three-year-old children by adopting a "minimalist" view of episodic memory based on its What–When–Where ("WWW": spatiotemporal plus semantic) content. We argued that the temporal element within spatiotemporal should be the order/simultaneity of the event elements, but that it is not clear whether the spatial content should be egocentric or allocentric. We also argued that episodic recollection should be configural (tending towards all-or-nothing recall of the WWW elements). Our first deferred imitation experiment, using a two-dimensional (2D) display, produced superior-to-chance performance after 2.5 years but no evidence of configural memory. Moreover, performance did not differ from that on a What–What–What control task. Our second deferred imitation study required the children to reproduce actions on an object in a room, thereby affording layout-based spatial cues. In this case, not only was there superior-to-chance performance after 2.5 years but memory was also configural at both ages. We discuss the importance of allocentric spatial cues in episodic recall in early proto-episodic memory and reflect on the possible role of hippocampal development in this process.

***Keywords*:** Episodic memory; Hippocampus; Deferred imitation.

## "Minimal" episodic memory in animals and children

AQ1 Endel Tulving's original definition of episodic memory was minimalist: "Episodic memory receives and stores information about temporally dated episodes or events, and temporal-spatial relations among these events" (Tulving, 1972, p. 385). It was minimalist in the sense of making no reference to the possession of concepts or to consciousness, in contrast to Tulving's later views (e.g., Tulving, 2005). This definition was interpreted by the comparative psychologists Nicola Clayton and Anthony Dickinson to mean that if an animal recalls "what" happened, "when" and "where" then it has fulfilled the original Tulving criteria. Indeed, they argued that a food-caching bird, the scrub jay, fulfils these criteria in so far as

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it remembers what kind of food was cached, how long ago and where it was cached (Clayton & Dickinson, 1998). This became known as What–Where–When (WWW) memory. The general assumptions behind the work were taken up by researchers on rat learning (Babb & Crystal, 2006; Eacott & Norman, 2004; Iordanova, Good, & Honey, 2008; Wright, 2013).

In an attempt to locate the above issues in relation to the early development of episodic memory in children, Russell and Hanna (2012; Russell, 2014) made the following proposal. If there is a minimal WWW memory in young children then we should regard this as only a prefiguration of true episodic memory. This is because such a form of memory may be unaccompanied by the kind of conceptual capacities associated with adult episodic recall such as the concept of a unique, experienced event causing a present memory (McCormack & Hoerl, 2001; Perner, 2001). The term we shall be using for such WWW memories is "proto-episodic". The term is needed to distinguish it from episodic recollection that the child knows to be such (hence, Tulving's, 2005, term "autonoesis"), which is likely to depend upon theory-of-mind insights to some degree, and which seems to begin after four years (e.g., Perner & Ruffman, 1995; Perner, Kloo, & Gornik, 2007).

The Clayton–Dickinson approach has its critics (e.g., Suddendorf & Busby, 2003), but the criticisms pertinent to the present studies were voiced by Russell and Hanna (2012). First, one can question the Clayton–Dickinson view of the temporal element (when = how long ago), given that there is no reason to believe that knowing how long ago an event took place is *constitutive* of episodic memory.[1] Second, and more generally, the Clayton–Dickinson interpretation of WWW is not based on any conceptual analysis of re-experiential memory. Russell and Hanna suggested that we should turn for this analysis to philosophy, and to Kantian philosophy in particular. From an analysis of the essential properties of a perceptual experience, one can argue that if episodic memory is indeed re-experiential then it will *inherit* these properties.

[1]The thought experiment: You have a re-experiential memory for event *E* and know it was a unique autobiographical event, but cannot recall whether *E* took place last week or a month ago. What warrant is there for denying that it is an episodic memory? The length of time between *E* and the present would appear to be a semantic matter.

Kant (1781/1998) claimed that experience is essentially spatiotemporal—this is the famous "a priori of space and time"— and in doing so took the temporal content to be the *order or simultaneity* of elements (things or actions) within an experience. Given this, if a memory is re-experiential then it should be the order or simultaneity of the actions or objects *within the episode* that will be recalled: these properties will be carried over from experience to re-experience.

With regard to space, it is far from clear whether it is egocentric or allocentric space that is supposed to be central to experience, and thus to re-experience. Setting to one side the philosophical issue of what Kant meant, or should have meant, by the spatial claim, one can express the underlying ambiguity this way: because experience is inevitably from a point-of-view, egocentricity is suggested, whereas at the same time experience is typically taken to be of an objective spatial world, which would suggest allocentricity. In this paper, *whether egocentric or allocentric spatial content is utilised in young children's episodic memory will be one of the central empirical questions to be addressed.*

The implications from the above position for researchers studying WWW are twofold: (1) the temporal element in WWW memory should be order/simultaneity of elements within the original event, and (2) whether the spatial content of the experience/re-experiential memory is allocentric or egocentric is an issue to be determined empirically. However, there would seem be a third characteristic of WWW episodic memory that pertains not to the content of the re-experiential memory but to how the WWW elements are related. The supposition is that they are related to one another holistically. The next section explains this claim.

## The putatively non-elemental nature of episodic memory

We will argue, after Russell and Hanna (2012; Russell, 2014), that for WWW memory to be truly episodic, the three components will tend to be recalled in all-or-nothing fashion, rather than as independent elements, given that events are experienced "as a whole." We offer three considerations in favour of this view.

In the first place, when Tulving originally drew the semantic-episodic distinction he wrote that "Semantic memory is the memory necessary for the use of language" (Tulving, 1972, p. 386), going on to explain how it must have a language-like format. Next, the symbolic format underlying language would seem to require the bringing of atoms of meaning into relation to produce molecular propositions. Accordingly, one can lay down a semantic trace of an event in other people by relating the event to them. And it falls out from the nature of language itself that this can be done bit-by-bit—elementally. Thus, if I relate an event to a friend I can say "It was a yellow van." "It was on my left." "It then signalled to turn right." By contrast, if the friend was with me at the time of the incident, these objects and these spatiotemporal facts will naturally be perceived and encoded together. It would be difficult, if not impossible, in this example, to see that it was a yellow van without seeing it on one's left. Of course, the friend's memory may lose these elements selectively, but this is a clear property of event encoding. To witness an event means to be presented with WWW together, whereas to be told about an event is to be presented with the event in clauses, element-by-element. Given this, a subject who is unable to lay down episodic traces will be unable to preserve the perceptual unity of the original experience, while perhaps recording nonetheless the elements as relatively independent entities.

Second, turning to animal learning, students of learning in the laboratory rat have traditionally drawn a distinction between models of learning in which stimuli are associated as distinct elements—"elemental" approaches—and models in which stimuli are represented as a single, blended unit—"configural" approaches. John Pearce (1994) is one of the more significant workers arguing for configural representation in the context of animal learning. Indeed, in the work of Iordanova, Burnett, Good, and Honey (2011) on "episodic-like" WWW memory in the rat, this distinction is drawn in the service of investigating how the existence of a configural relation between the WWW elements depends upon the integrity of the hippocampus. They refer to Pearce's (1994) model in which each element is linked to a fourth unit that is common to all but independent of each. In the latter case only, the WWW memory forms a unity.

Applied to WWW memory in development, the empirical claim is that if WWW memory is episodic it will be configural not elemental. There is some debate, however, over the degree to which *adult* episodic memory is non-elemental (Brewer & Dupree, 1983; Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Fisher & Chandler, 1991; Newcombe, Lloyd, & Ratliff, 2007) or fragmented (Trinkler, King, Spiers, & Burgess, 2006; Wagenaar, 1986). AQ3 However, what elementality exists in adult episodic memory may be a function of its concept-exercising and strategic nature, which are features not shared by WWW memories of the proto-episodic kind, on the present view.

A third motivation for this configural analysis is offered by the work of Iordanova et al. (2011) and others on the role of the hippocampus in WWW memory in the rat. If indeed the kind of WWW memory under consideration is essentially a form of hippocampally mediated memory then configurality is what one would expect. Neural network modelling of hippocampal function has converged on the view that one of its core functions is that of pattern completion by auto-association, such that given a subset of the input the network will output the compete pattern (McNaugton & Morris, 1987; Morris & Frey, 1997; Rolls & Treves, 1998). Our method of assessing non-elementality/configurality depends upon an assumption very close to autoassociation.

## The present empirical strategy in the context of related research findings

In the light of these considerations, our empirical strategy for examining WWW proto-episodic memories in children of two and three years of age was to employ a deferred imitation[2] procedure in which the children watched a demonstration on the first day that produced an interesting effect, after which they were invited to reproduce the effect on the second day. The demonstration had a WWW structure in the following respects: the What element was either an object (a computerised icon, in Experiment 1) or an action (produced on a lever, in Experiment 2). The When element was the order in which the objects were moved or the actions were performed. The Where element was essentially egocentric in Experiment 1, whereas allocentric cues were afforded in Experiment 2. Finally, in both studies, we investigated whether recall was elemental or configural (borrowing this term

[2]This term is not ideal given that our procedure might be regarded as "observational causal learning" (as in Meltzoff, Waismeyer, & Gopnick, 2012). However, as the term "deferred imitation" is used in the memory, rather than the causal, literature, we have used that. Note too that because the children are not given the opportunity to act on the materials before the retention interval, as in Bauer's (2013) procedure of "elicited" imitation, we do not use the term elicited imitation.

from the animal literature) by the application of a statistical model.

Because we wished to have a measure of episodic memory as unaffected as possible by semantic scaffolding, we ensured that the WWW elements had no natural relationships among them. That is to say, the causal relations between the WWW elements were semantically arbitrary rather than meaningful. Meaningful relations among modelled elements in imitation studies are referred to by Bauer and colleagues (Bauer, 2013, for a recent review) as "enabling relations." We will adopt Bauer's term.

We now place this strategy within the context of what is known about the deferred imitation of sequences in infants and toddlers and about preschool children's WWW memory. First, many of the elements of the proto-episodic memory sketched at the beginning of this section are in place in infants and toddlers: (1) recall of actions and placements over long periods, (2) doing so in the correct order, (3) recalling complex sequences after a single exposure and (4) recalling the modelled events in a declarative format. As for (1), not only can infants remember individual actions for delays lasting months (e.g., Bauer, Wenner, Dropik, & Wewerka, 2000), but there is reason to believe that 14-month-olds, at least, can recall not only what the props afford but particular bodily movements of the modeller (Meltzoff, 1988). In (2), although it is clear that young children's delayed recall of sequences is much more successful if the sequences contain enabling relations (e.g., Bauer, Hertsgaard, & Werwerka, 1995), the delayed recall of arbitrarily ordered sequences is possible in older infants and toddlers and is well in place by the end of the second year (Bauer, Hertsgaard, Dropik, & Daly, 1998; Wenner & Bauer, 1999). As for (3), children of at least 16 months recall single-exposure actions over one month (Bauer & Leverton, 2013). Finally, the question—(4)—of whether young children's recollection of action sequences is in a declarative format can be answered positively. Bauer, Wenner, and Kroupina (2002) report that three-year-old children, who have acquired the verbal skills to do, so can talk about the experiences they had taking part in deferred imitation studies at 20 months.

With regard to the final point, although Bauer et al.' s (2002) study suggests that the kind of memory evoked in toddler's deferred imitation studies may indeed be semantic declarative (in a language-accessible format; see above discussion of Tulving, 1972), a question hangs over whether it is in an episodic declarative format—whether there is true re-experiential memory in young children. Answers to this specific question have tended to employ a WWW framework. The following studies are notable. First, Hayne and Imuta (2011) used a hide-and-seek procedure with three- and four-year-olds, in which What was the kind of toy hidden, Where was the rooms in which toys were hidden and When was the order of the hiding. Three-year-olds struggled with the When component. This divergence between three- and four-year-old performance was replicated in another study from this laboratory (Scarf, Gross, Colombo, & Hayne, 2013) AQ4 using a "spoon-test" methodology (Tulving, 2005) in which the functional item referred to a past event: only four-year-olds could retain the relevant event for 24 hours. Hayne and Imuta's study fulfils many of the desiderata sketched above. However, apart from differing from the present task in using search (and verbal recall), this study did not take the temporal element to refer to micro-events within one demonstration, but to the order of three hiding events. Newcombe, Balcomb, Ferrara, Hansen, and Koski (2014) used a WWW design in which one of the Ws was Which-context. Children from 15 months to three years had to recall that toy X was in box A in room 1 but in box B in room 2, with toy-type being What, box being Where and room being Which-context (analogous to a rat study by Eacott & Norman, 2004). Success on this task emerged within the second year of life. At the very end of this paper, we will ask whether it is possible to regard the Which-context element as one of simultaneity, and thus as a *temporal* element.

In the light of this it can be said that although infants and toddlers have a form of event memory that has some features of episodic recall and although preschoolers successfully integrate semantic and spatiotemporal elements of events to some degree, we have as yet no evidence that children under four years show WWW memory of the kind outlined at the beginning of this section. As initially noted in "minimal" episodic memory in animals and children section, four years is the age at which evidence appears for a more conceptually mediated kind of episodic recall (Perner, 2001; Perner & Ruffman, 1995; Perner et al., 2007). "Proto-episodic," recall, is taken by us to mean the kind of non-conceptual episodic memory that emerges before this age.

## The first study, spatial content and the elemental model

The two experiments to be reported here differed centrally in terms of the kind of spatial information presented to the child. In the first study, the spatial information was two-dimensional (2D) and in the second it was three-dimensional (3D). In the first case, spatial cues were egocentric to the extent the locations were fixed in terms of left/right and above/below (e.g., top left-hand corner). In the second case, by contrast, actions were carried out on an object in a room so they could be coded as "next to the door/window/bookcase" and so were allocentric to that extent.

Our first WWW binding task was presented on a touch-screen. In this task, children were shown, on day 1, that it was possible to make the computer play a jolly song and show a smiley face by moving icons on the screen to corners in a certain order. The spatial cues were the four corners of the screen (above-left, above-right, below-left, below-right), the temporal cues were the orders in which the icons had to be moved (e.g., pig-icon or monkey-icon first) and the orders in which the locations had to be visited (e.g., top-right before bottom-left) and the semantic content was the two icons. The children had to reproduce the icon movements on the second day in order to activate the song and picture. This is, therefore, a test of spatiotemporal-to-semantic binding.

Before passing on, it should be cautioned that it is a difficult matter to fix cues as *purely* egocentric. As long as a participant can regard points in space defined by above/below and left/right as locations at which things can be located, the purity of the egocentric coding can break down. For example, in moving an icon to the top right-hand corner, the child is free to regard this corner as a landmark even if what is "top right-hand" would alter if the screen were moved around 90°. They could regard a particular corner of the screen as a landmark cue, despite it not being perceptually distinctive. For this reason, we shall describe the studies as differing in terms of 2D/3D and leave the full treatment of egocentric versus allocentric coding to the General Discussion.

In a control condition, we presented children with a task that was structurally similar to the WWW task in so far as icons had to be manipulated on a touch-screen, but which had no spatiotemporal content. This is to say that recall of locations or orders was not necessary in this task, only the recall of object–object relations. This was a *What–What–What* task.

We used statistical modelling to determine whether recall was or was not elemental. Our elemental model assumed that recall of each W element was independent of the others. If this assumption is correct then the chance of correctly recalling (say) two of the W elements should be the simple product of the chance of correctly recalling each of them. By "chance" here we intend the post-hoc probability of a group of children recalling an element. That is to say, if the children are recalling each W in isolation from the others then the chance of recalling more than one of them is fully predictable by multiplication. For example, if a third of the group recalls one W then the chance of doing so is 0.33, and if a half of them recall another W then the chance of their doing so is 0.5. On an elemental model then, there should be a 0.165 ($0.33 \times 0.5$) chance of children recalling both. If, however, the probability of recalling one W is affected by the probability of recalling another, as in configural recall, then this will not hold. If recall is configural then there will be no fit to the elemental model. In the Results section of Experiment 1, we give a detailed account of how the elemental model gives rise to predicted recall scores which can be compared with observed scores.

## Predictions

Based on the above analysis, it was possible to make the following predictions about the outcome of Experiment 1:

(1) If episodic memory inherits the spatiotemporal nature of the original experience and if the spatial content can be coded in 2D space (with the temporal content being captured by intra-event order), there should be a clear divergence in developmental trajectory between the WWW and the What–What–What tasks. This is because, on the present analysis, the former will be tapping a form of episodic memory and the latter will not.

(2) If a hallmark of early WWW memory is its configural nature then there should be evidence for this form of memory in the performance of the children on the WWW task, but no evidence for it in the

What–What–What task. Performance on the former task should fail to conform to an elemental model, but performance on the latter should conform to it.

# EXPERIMENT 1

## Method

*Participants*

A total of 242 two- and three-year-olds (118 females) from a city in eastern England were recruited for this study. The children were recruited through local nursery schools and playgroups, and through posters and fliers. The parent or caretaker received £8 travelling expenses if they travelled to the laboratory. The sample was predominantly middle class and European in origin. Of the initial sample, 18 were excluded from the final sample, either for failing the warm-up task (2), refusing to participate on day 2 (9), equipment failure/experimenter error (6) and interfering with the demonstration on day 1 (1), making a final total of 224 participants. It is likely that the children were familiar with touch-screen technology, if not from iPads then from nursery computers or their parents' smartphones.

We consider the children within six-month age bands when reporting success on the task, and consider them in two ages for application of the elemental model, as the model was more meaningful with a larger sample size. There were 56 children in the 24- to 29-month age range ($M$ = 26.4 months, $SD$ = 1.92 months), 56 in the 30- to 35-month age range ($M$ = 32.3 months, $SD$ = 1.61 months), 56 in the 36- to 41-month age range ($M$ = 38.9 months, $SD$ = 1.65 months) and 56 in the 42- to 47-month age range ($M$ = 44.6 months, $SD$ = 1.65 months). Half of the children in each age band were randomly assigned to the WWW condition and half were assigned to the What–What–What condition: 28 children in each at each age level for each task.

*Apparatus*

The study was conducted on an Apple iPad touch-screen computer (screen 19.7 × 14.8 cm). A specially programmed application was used for this purpose. Children sat directly facing the touch-screen, which was either placed on a table or held by the experimenter. The computer recorded all responses automatically.

*Design*

There were two between-subjects variables. These were age (two/three years) and task (WWW or What–What–What). Children were randomly assigned to one of the tasks.

*The tasks*

*Warm-up task.* Children first completed a warm-up task in which four coloured shapes (a red triangle, a yellow circle, a green square and a blue cross) rotated around the centre point of the touch-screen and four coloured boxes, each one corresponding to the colour of a shape, were located in each of the four corners of the screen. The goal was to touch and drag each shape into the corner box of the corresponding colour. When a shape was correctly placed in its colour-matched box, feedback was given (a "thumbs up" icon appeared and plus the words "Well done!"). No feedback was given when shapes were placed in unmatched boxes. After each trial, the shape that had been moved returned to its original position and all the shapes recommenced rotation. The task was designed to give children experience of dragging icons from the centre of the screen to the corners. The spatial arrangement of the shapes and boxes was congruent with the arrangement of the animal and box icons in the experimental tasks. Children who failed the warm-up task were those who were simply unable to learn the principle of matching the colours. Additionally, verbally prompting them was inefficacious. This is in contrast to those children who simply refused to touch the screen but who were responsive to verbal cues and could tell the experimenter where to move the colours—see following paragraph.

Twelve children who refused to move the icons in the warm-up completed the task by responding to experimenter prompts. They responded by pointing to the icon and then to the box to which the icon should be moved after verbal prompts. These were prompts such as "Which one shall I pick?" and "Where do I put this one?" The experimenter moved them on the child's instructions.

*WWW task.* Figure 1a shows a screen configuration of the WWW task. In each of the four corners of the screen there was a blue box. The animal icons moved slowly clockwise around the centre point of the screen at a speed of

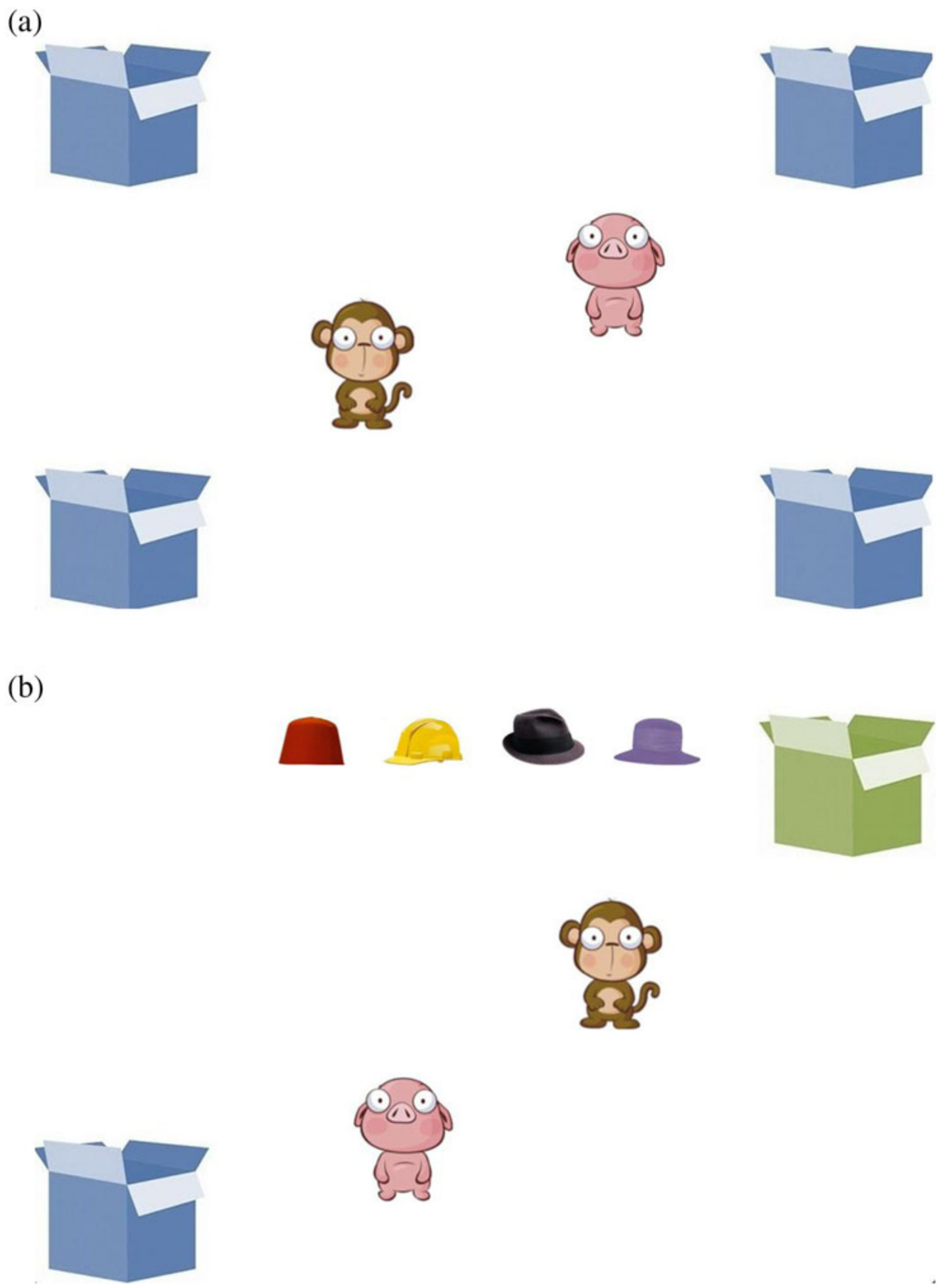


**Figure 1.** (a) Screen-shot of WWW task. (b) Screen-shot of What–What–What task.

1 revolution per 18 seconds. The goal of the game was to make "a funny song" play by performing a particular sequence of actions. The correct sequence involved placing one of the animals in one of the boxes (by touching and dragging it to that location) and then placing the second animal in another of the boxes. The orders in which the animals were moved and the box location they were moved towards were counterbalanced across participants. When the sequence was complete a smiling face appeared on the screen accompanied by a 10-second clip of the chorus from the "Laughing Policeman." When an animal was touched, both animals stopped rotating. Once the first animal had been placed in a box and released, it disappeared for two seconds and then reappeared in its original location, after which both animals recommenced rotation. Only then could the second move be made. Accordingly, participants were free to move the same animal

twice. They were also free to place the second animal they had moved into the same box into which they had placed the animal they had moved first. The experimental sequence was demonstrated twice to children. After a 24-h delay, they were given the opportunity to "make the funny song play" themselves. The song always played after two animal-to-box moves had been made, irrespective of which animal(s) were moved to which box(es) and in which order. The 12 children who had refused to touch the iPad on the warm-up received verbal prompts to elicit pointing, as they had done in the warm-up. Prompts were: "Which animal do I have to pick?" and "Where do I put this one?" The experimenter completed the actions as directed by children and the iPad recorded the responses as it did on all other trials.

*What–What–What task.* Figure 1b shows a screen configuration of the What–What–What task. As with the WWW task, the animals rotated around the centre point of the screen. Four hats (yellow hard hat, red Fez, black trilby and purple fedora) were arranged in a line across the top of the screen. The order in which the hats were arranged was randomised from trial to trial with the constraint that the same order never occurred on two consecutive trials. A green box and a blue box were located in two of the four corners. As with the hats, each box was randomly assigned to one of the four corners with the constraint that they did not reappear in the same corner from trial to trial. To make the "funny song" play in this game, a hat was placed on the head of one of the animals and that animal was then moved to one of the boxes. The animals could not be moved unless a hat had been placed on them. Then a second hat was placed on the head of the second animal and that animal was placed in the second box. When the first animal had been placed in one of the boxes it did not return, leaving a single animal. Children were presented with two demonstrations of the two hat–animal–box pairings. However, as the order in which the animals were placed in the box was irrelevant, the second demonstration reversed the order of the first demonstration. So that if children had been shown *Red Hat–Pig–Green Box* and then *Yellow Hat–Monkey–Blue Box* on the first demonstration they then saw *Yellow Hat–Monkey–Blue Box* and then *Red Hat–Pig–Green Box* on the second demonstration. Note that although the WWW were semantic rather than spatiotemporal–semantic, there were no enabling relations (see The Present Empirical Strategy in the Context of Related Research Findings section) fixing location or order.

The probability of passing each of the tasks by chance was 1/64.[3] Both tasks allow for a scoring system in terms of individual elements that were recalled, which could then be used to assess whether recall of these elements was elemental. In the WWW task, children were given a point for correct animal selection (i.e., selecting each animal on different occasions rather than selecting the same animal twice), a further point for selecting the animals in the correct order, a point for selecting the correct locations and a point for selecting the locations in the correct order. Children who recalled the exact sequence scored four points. In the What–What–What task, children received a point for recall of the correct hats, a point for placing the hats on the correct animals and a point for placing the animals in the correct box, making a possible total of three points. Note that although one task was scored out of fewer points than the other, success by chance was equally likely in each. The difference in total number of points was inevitable given the temporal structure of WWW, in which both location and icon choice have to be bound to order. The elemental model that was applied to these scores will be described in the Results section.

### Procedure

Performance was recorded automatically on the computer. The majority of children (75%) were tested at nursery, whereas the remaining 25% of the children were tested in their own homes or in our laboratory. The testing location was always the same from day 1 to day 2. Testing always began with the colour-matching warm-up game. The experimenter demonstrated touching and dragging the shapes into the colour-matched boxes and then invited children to try. Once children had successfully moved all four shapes

[3] In the What-When-Where task, there was ½ chance of picking the correct icon animal initially, then a ¼ chance of moving it to the correct corner, then another ½ chance of picking the second animal correctly, followed by a ¼ chance of moving it to the correct corner. In the What-What-What task there was a ½ chance of picking one of the two correct hats, followed by a ½ chance of putting this on the correct animal, followed by a ½ chance of putting this in the correct box; after this a ¼ chance of picking the other correct hat. As there was now only one animal remaining this was followed by a ½ chance of putting the hat-wearing animal in the correct box.

into their respective boxes at least once they progressed on to the experimental task. As noted, a small number of children (12) refused to touch the screen during the warm-up game. These children were encouraged to point to the boxes where the shapes should be placed ("Can you show me where the [blue] triangle goes?"). If they did this successfully (correctly indicating which box to place each shape in at least once), they progressed to the experimental task. We analysed the data both with and without the data from these children included (see below).

Once they had completed the warm-up task, the children heard:

> We are now going to play a new game. This new game is with animals. In this game we will make a funny song play. Would you like to hear the funny song? There is a special way to make the funny song play. I am going to show you how to do it.

The application was then opened to reveal the experimental task. In both experimental tasks, children were asked to name the animals, in order to maintain interest. In the WWW task, the experimenter then brought the four corner boxes to the children's attention: "Look at these four boxes" (experimenter points to each box in turn). In the What–What–What task, the experimenter pointed to the four hats, naming each one by its colour and then pointed to the boxes, labelling them by colour. All children were then asked: "Do you want to see how to make the funny song play? This is how we do it." In the WWW task the experimenter, while performing the demonstration, told children, "First we move this one to this box here. Then we move this one to this box here." In the What–What–What task, the experimenter told children, "This hat goes on this one here and he goes into this box here. And this hat goes on this one here and he goes into this box here." Children were then given a second demonstration with the same instructions. At the end of the second demonstration, children were told by the experimenter "Tomorrow I will come back and we will play the game again. It will be your turn to make the funny song play."

Note that because we wanted to maximise egocentric coding of spatial cues on these tasks (e.g., top-right hand, bottom left-hand), we did not place the screen near landmark cues, but on a bare desk. Otherwise, it was held before the child.

On day 2, the children were first given the opportunity to play the warm-up game. After completing four warm-up trials, the experimenter then told children that they were going to play the other game. The relevant application was then opened. If children needed further encouragement they were told, "What do we need to do in this game? How do we make the funny song play?" The song played after two animal-to-box moves had been made, irrespective of whether or not children had performed the demonstrated sequence. Children who had refused to touch the screen in the warm-up game were asked, "Can you show me how to make the funny song play? What do I have to do?" If children pointed to an animal in the WWW condition, the experimenter would then ask, "What do I do with this one?" If the child pointed to one of the boxes the experimenter moved the animal to that box. Similarly, in the What–What–What condition, if the child pointed to one of the hats but did not then indicate which animal to place the hat on, the experimenter would ask, "What do I do with this one?"

## Results

### *Performance on the tasks*

Preliminary analysis revealed that the location of testing (nursery versus home or lab) had no effect on pass-rates on either task. Furthermore, none of the analyses reported below were affected by excluding children who gave pointing responses after verbal encouragement (described at end of the Methods section) rather than motor ones. The percentages of children passing each task within the four age bands are given in Table 1. By "passing" the task we mean reproducing the complete WWW set.

Inspection of Table 1 suggests that performance differed little between the tasks at each age. Indeed, the tasks did not reliably differ in difficulty overall, $\chi^2(1, N = 224) = 0.42$, $p = 0.52$.

**TABLE 1**
Percentage of children in each condition who passed the two touch-screen tasks (numbers of passes in parentheses)

| *Age (months)* | *What–When–Where* | *What–What–What* |
|---|---|---|
| 24–29 | 7 (2/28) | 4 (1/28) |
| 30–35 | 14 (4/28) | 11 (3/28) |
| 36–41 | 29 (8/28) | 36 (10/28) |
| 42–47 | 29 (8/28) | 43 (12/28) |
| All children | 20 (22/112) | 23 (26/112) |

There was no significant effect of age on pass-rate in the WWW task, $\chi^2(3, N = 112) = 6.11$, $p = 0.11$, although there was an effect of age on pass-rates in the What–What–What task, $\chi^2(3, N = 112) = 17.03$, $p < 0.01$.

### *Comparing performance against chance*

Recall that the probability of passing each of the tasks by chance is 1/64. Comparisons against chance within each age band were by one-tailed binomial tests. The proportion of young two-year-olds who passed the WWW task failed to reach significance ($p = 0.07$). The proportion of younger two-year-olds who passed the What–What–What task was likewise not significantly above chance ($p = .36$). The proportion of older two-year-olds who passed the WWW task was significantly better than chance ($p < 0.01$), as was the proportion of older two-year-olds who passed the What–What–What ($p < 0.01$). Performance was also superior to chance in all the higher age bands.

### *Applying the elemental model*

The percentage recall of the individual elements and the relevant bindings (order is relative to both icon and action, and icon choice is relative to order and location) are shown in Table 2. These are the data that went into the elemental model for the WWW task.

The elemental model was designed to determine whether recall of any given element was independent of recall of any other element. We will illustrate how this model was applied to the WWW data, with the same basic procedure being applied to the What–What–What data.

In the WWW task, children were given one point each for correct recall of both locations (L), correctly choosing different icons for each movement (I), binding locations correctly to order (LO) and binding icons correctly to order (IO). Scores, therefore, ranged from 0 to 4.

There were two possible ways for children to score one point: by placing the same icon in the correct locations but visiting those locations in the wrong order or by using both icons but in the wrong order and placing (at least one) them at the wrong location. There were three possible ways for children to score two points: they could place both icons in the correct order at the wrong locations; they could visit the correct locations in the correct order but using the same icon twice; they could visit the correct locations in the wrong order, using both icons but also in the wrong order.

If children recalled both locations correctly and used different icons at the two locations then they necessarily scored a minimum of two points. Whether they scored more than two points was determined by the order in which they visited the locations and the order in which they manipulated the icons. If they got the order correct for location but not for icons, they would score three. Conversely, if they were correct for icon order but incorrect about location order, they scored three. Finally, if they were correct both on icon order and location order they scored three points.

The strategy in the elemental model was the following. First, the probability that children at each age would be correct on each of the elements was worked out from the data. For example, if a third of the children at one age level were correct on location order, this would be a probability of 0.33. If we assume that the different components of the task are recalled independently from one another then we can model the probability of obtaining recall scores (from 0 to 4) by multiplying the observed probabilities of recalling each component to yield conjoint probabilities, as in the following examples. (See the Appendix for how each of the 5 (0, 1, 2, 3, 4) score probabilities was worked out.) The expected probability of scoring 0 is the product of the probability of getting location incorrect and of wrongly choosing the same icon each time. This is 1 minus the probability of getting location correct times 1 minus the probability of getting icon

**TABLE 2**
Percentage of children recalling elements and element combinations on the WWW touch-screen task at two ages

| | *What*[a] | *What–When* | *What–Where* | *Where* | *Where–When* | *What–When–Where* |
|---|---|---|---|---|---|---|
| 2-year-olds | 73 | 48 | 20 | 34 | 18 | 11 |
| 3-year-olds | 89 | 57 | 38 | 61 | 41 | 29 |

[a]Note that unbound recall of What in this task means recalling that each icon should be manipulated only once. Children who failed to recall What moved one icon twice.

manipulation correct ($P$ = the empirical probability of getting an element correct): 1–$P$(L).(1–$P$(I). The expected probability of scoring four points is equal to the probability of getting location correct and icon manipulation correct and location order (given location) correct and icon manipulation correct: $P$(L). $P$(I). $P$(LO/L). $P$(AO/I). The resulting probabilities were then taken as the expected proportions of children within an age level who would obtain these scores, expressed as numbers of children ("Expected"), which were then compared against the number of children actually obtaining these scores ("Observed").

Because the number of the expected frequencies within some cells was very small, it was not possible to run this model at each of the six-month age bands. Accordingly, the model was run at age 2 and age 3. See Figure 2 for the comparisons of Expected and Observed scores for age 2.

A chi-square test of goodness of fit revealed that there was no significant difference between the distribution of Expected and Observed recall scores, $\chi^2(4, N = 56) = 5.13$, $p = 0.22$.

The Observed and Expected recall scores for three-year-olds on the WWW task are shown in Figure 3.

A chi-square test of goodness of fit revealed that there was no significant difference between the distribution of Expected and Observed recall scores for the three-year-olds, $\chi^2(4, N = 56) = 2.73$, $p = 0.6$.

For the What–What–What task, children were given 1 point for recalling each of the following elements: the correct hats, the correct animal–hat pairings and the correct animal–box pairings. Possible recall scores ranged from 0 to 3 with a maximum score of three for children who pass the task.

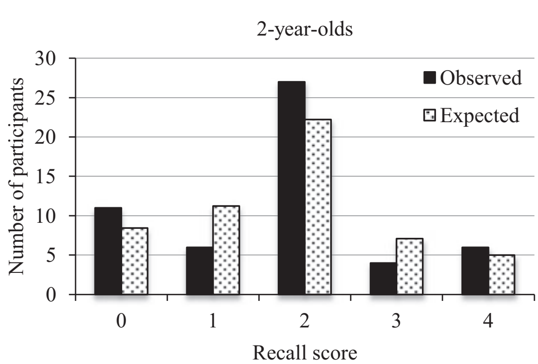


**Figure 2.** Observed scores against those expected on the elemental model for two-year-olds on the WWW task.

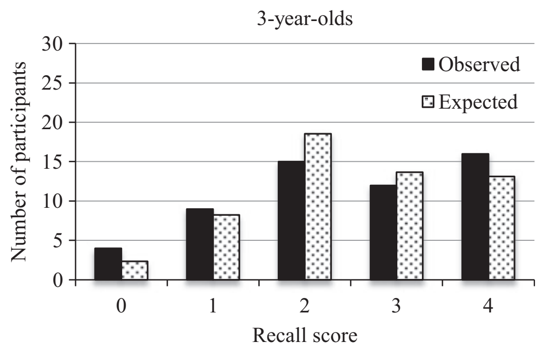


**Figure 3.** Observed scores against those expected on the elemental model for three-year-olds on the WWW task.

The percentage recall of the individual elements and the relevant combinations are shown in Table 3. These are the data that went into the elemental model for the What–What–What task. Figure 4 shows the Observed and Expected distribution of recall scores on the What–What–What task for two-year-olds.

A chi-square test of goodness of fit revealed that there was no significant difference between the distribution of Expected and Observed recall scores, $\chi^2(3, N = 56) = 0.09$, $p = 0$ .99.

Figure 5 shows the Observed and Expected distributions under the elemental model for recall scores of three-year-olds on the What–What–What task.

A chi-square test of goodness of fit revealed that there was no significant difference between the distribution of Expected and Observed recall scores for this age group, $\chi^2(3, N = 56) = 2.92$, $p = 0$ .4.

## Discussion

Neither prediction was confirmed. There was no difference in performance between the WWW group and the What–What–What group, suggesting that spatiotemporal content was playing no

**TABLE 3**
Percentage of children recalling elements and element combinations on the What–What–What touch-screen task at two ages AQ19

| | *Hats* | *Hats–animal* | *Animal–boxes* | *Hat–animal–box* |
|---|---|---|---|---|
| 2-year-olds | 32 | 21 | 38 | 7 |
| 3-year-olds | 57 | 52 | 64 | 39 |

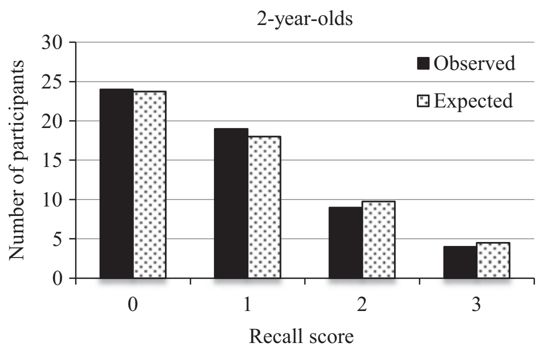


**Figure 4.** Observed scores against those expected on the elemental model for two-year-olds on the What–What–What task.

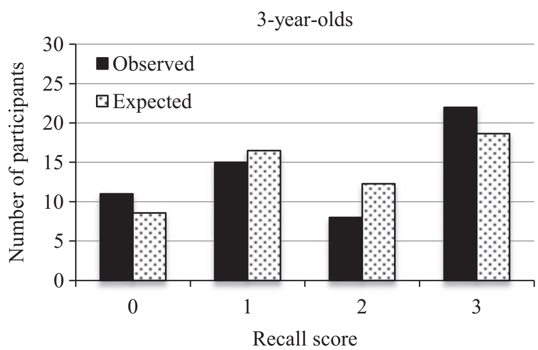


**Figure 5.** Observed scores against those expected on the elemental model for three-year-olds on the What–What–What task.

role in recall. Also, there was no evidence for non-elemental/configural memory in the WWW group.

In considering the reasons for this outcome, it is natural to turn to the question of the kind spatial content in the tasks, and to the fact that the spatial environment was 2D, an environment that naturally affords egocentric spatial coding. Given this, we asked whether we would find evidence for configural episodic memory when children were presented not with a 2D medium without landmark cues, as in Experiment 1, but with a 3D layout (a room) in which it was possible to code the spatial location of the semantic element by utilising allocentric cues such as "near X." In this situation, "what" was a kind of action rather than a kind of object.

There were two main reasons why we decided to make the semantic element ("What") an action rather than an object in Experiment 2. In the first place, in order to parallel the iPad task with objects it would have been necessary to arrange things such that the initially placed object returned to its original location for the second choice. Second, we had evidence from a previous deferred imitation WWW study using an action that young children accommodate well to such a situation and find it meaningful (Russell & Davies, 2012).

In the laboratory, children were presented with a "music box" with an upright handle at each of the four sides that afforded two actions equally—pumping and twirling (see Figure 6). The experimenter showed the children that pumping one of the handles and then twirling another (or vice versa) turned the box on. They returned to the lab the next day and were invited to make the box come on again.

Note that in this kind of demonstration there will necessarily be allocentric cues, given that the pumping and twirling will be done near a feature of the room (e.g., near the door/the window). However, it was also possible to provide the option of coding the location of the actions egocentrically. Thus, if the child watches the demonstration from a *fixed point* then each action would be "on my left", "on my right", "near me" or "far from me". This was one of our two conditions: the *viewer-centred* condition in which children remained in a chair and watched the actions from that point, side-on to the box. In the other condition, by contrast—the *object-centred* condition—the child followed the experimenter round the box as he performed the actions. In this condition, egocentric coding was not possible as it

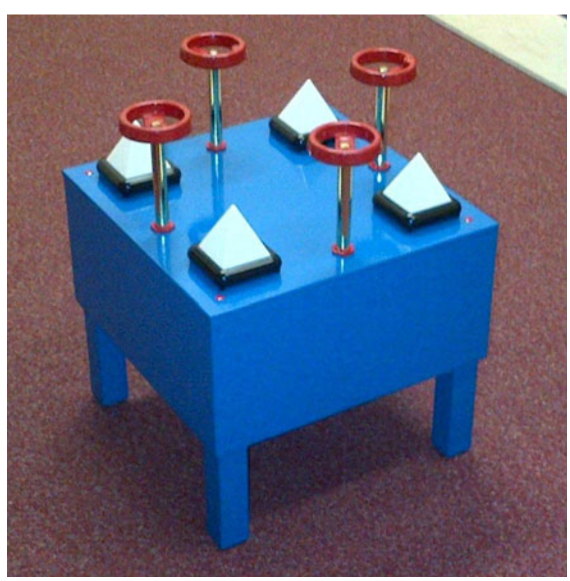

**Figure 6.** The music box.

was in the viewer-centred condition. If children are entirely reliant upon allocentric cues, and do not avail themselves of egocentric ones, then there should be no difference in performance on the two conditions, as it would seem to be equally possible to code, say, "pumping near the door" in the two cases.

Next, what warrant do we have for assuming that children of this age can indeed utilise allocentric cues like "near the window?" Nardini, Burgess, Breckenridge, and Atkinson (2006) have shown that children of at least three years of age can utilise what they called "environmental" cues of this kind, although struggling to code location by more local "intrinsic" allocentric cues. Their task was a demanding one in which objects had to be retrieved after self- or display-reorientation, or both. It is a reasonable conjecture that under-3s will be able to utilise such environmental cues in a simpler task without reorientation conditions (see Newcombe, Uttal, & Sauter, 2013, for a review supporting this conjecture).

# EXPERIMENT 2

## Method

### *Participants*

A total of 131 two- and three-year-olds (62 females) from a city in eastern England were recruited for this study. The children were recruited through local nursery schools and playgroups and through posters and fliers. The parent or caretaker received £8 travelling expenses. The sample was predominantly middle class and European in origin and was divided into four six-month age-bands. Eight children in the youngest age group (24–29 months) were removed from the final sample for either refusing to engage with the music box on the second visit (3), inattention during the first visit (2), parental interference (2) or experimenter error (1). Two children were removed from the 30- to 35-month age group for inattentiveness during the first visit. Six children were removed from the 36- to –41-month age group (parental interference at testing (3), refusing to engage with music box during the second visit (2) and inattention during the first visit (1). Three children from the older age group (42–47 months) were removed due to experimenter error. "Inattention" included children who refused to sit on the chair and observe, immediately playing with the box upon its unveiling, or refused to follow the experimenter round the box or listen to the story.

We consider the children within six-month age bands when reporting success on the task, and consider them in two ages for application of the elemental model, as the model was more meaningful with a larger sample size. The final sample of 112 children comprised 28 children in the 24–29 month age range ($M$ = 26.1 months, $SD$ = 1.7 months), 28 in the 30–35 month age range ($M$ = 31.8 months, $SD$ = 2.3 months), 28 in the 36–41 month age range ($M$ = 38.4 months, $SD$ = 1.9 months) and 28 in the 42–47 month age range ($M$ = 44.3 months, $SD$ = 1.6 months). Half of the children in each age band were randomly assigned to the *viewer-centred* condition and half were assigned to the *object-centred* condition: 14 in each.

### *Apparatus*

A special music box was constructed for this study (see Figure 6). The sides of the box were 46 cm in length and the box measured 40 cm in height. Four handles protruded from the top of the box. Each handle was located 5 cm from the edge of one side of the box, equidistant from the two nearest corners. The handles had a central column 16 cm in length with a wheel 10 cm in diameter, fixed on top of the column. The handles afforded two actions: they could either be pumped up and down or rotated around the column. In addition, there were four lights located on top of the box, one at each corner. When activated, the box played music and the lights flashed in a variety of colours.

### *Design and procedure*

There were two test sessions separated by approximately 24 hours. In the first session, the experimenter demonstrated how to turn on the music box, by (for example) pumping first at north and then twirling at east, or pumping at south and twirling at north, using all possible pairings. In the second session, the music box was reintroduced to children and they were invited to turn it on. To do so they had to perform the correct actions, at the correct locations in the correct order. The child's perspective at demonstration was manipulated. In the *viewer-centred* condition, children remained seated in a chair while the experimenter moved around the box to the first and then the second handle. In the *object-centred* condition, the child accompanied the experimenter as he walked to the first and then to the second handle. Thus, in the object-centred condition the child was always directly facing the handle that the experimenter was manipulating.

Testing took place in the playroom in our laboratory. Children were accompanied by a parent/caregiver at all times during both sessions. Each session began with a 5- to 10-minute warm-up period, in which the experimenter engaged the child in free play with toys in the room. At this stage, the music box was in the centre of the room but was covered with a sheet. No reference was made to the music box at this stage unless children expressed curiosity about what was under the cloth (very few children did). Once children were deemed by the experimenter to be comfortable and attentive they were invited to sit in a "special chair" next to Harry the Hippo, as Harry wanted to show them his new toy. This chair faced the box adjacent to one of the four sides of the box (counterbalanced across all participants).

Children were told that Harry the Hippo (a cloth doll in the room) had recently celebrated his birthday. They were shown a photograph of Harry beside a gift-wrapped present and told that this was Harry receiving his birthday present. They were then told that Harry's present was under the cloth and that Harry wanted to show them it. The cloth was then removed to reveal the music box. The experimenter brought children's attention to the four handles. He counted the handles, touching them one at a time. The experimenter then demonstrated how to make the handles move. This demonstration was always performed on one of the two handles not used in the subsequent test procedure. Children were told that "the handles can move like this," at which point the experimenter either pumped or turned the handle, "or the handles can move like this," at which point the second action was demonstrated. The order in which the two actions were demonstrated was counterbalanced across participants.

The experimenter proceeded to tell the children:

> there is a special way of turning on the music box. But Harry does not know how to turn on the music box. Harry is very sad about this. But I am going to show Harry, and I am going to show you too, how to turn on the music box. Would you like to see how to turn on the music box?

Children were then told that "the important thing is that you only need to touch two of the handles, these two here", at which point the experimenter pointed to the two handles to be used in the test demonstration.

At this point, the experimenter knelt beside the first handle used in the experimental sequence and invited children in the object-centred condition to stand beside him. Children in the viewer-centred condition remained seated. The experimenter then told children "This is how you turn on the music box. First, you move this one like this", at which point he either pumped or turned the first handle for approximately one to two seconds. The experimenter then moved so that he was kneeling adjacent to the second handle (accompanied by children in the object-centred condition), and said "and then you move this one like this," at which point the second action was performed on the second handle for approximately one to two seconds. After a delay of approximately one second from the completion of the second action, the box began to play music and the lights on top flashed different colours. The music and lights were, in fact, surreptitiously controlled by a remote device in the experimenter's pocket. After about 20 seconds, the music and lights stopped. The experimenter then said to the child he would show them once more how to turn on the music box. Children were invited to sit in the chair beside Harry (if they had been standing the in object-centred condition) and then they were given the same demonstration as before with the same instructions. The music played again for a further 20 seconds approximately. The order in which the two actions (pumping and turning) were performed was counterbalanced across participants, as was the identity of the two handles used in the demonstration. For half of the children in each condition, the first action was performed on the handle adjacent to the chair in which they were sitting (i.e., their starting point in the object-centred condition). For the remaining half, neither the first nor second action was performed on the handle adjacent to the chair in which they sat. The two actions were never performed on the same handle and the location of the second action was counterbalanced among the three other handles.

After the music stopped playing, the second time the experimenter informed the child that he thought that the music box needed new batteries as it has not been working very well. The experimenter then covered the music box with the sheet and told children that he would buy new batteries for the music box and that they could come back tomorrow to play with it once it had been fixed.

Children returned to the lab 24 hours later with their parent/caregiver. After a brief warm-up period, children were invited to sit beside Harry the Hippo. The location of the chair and music box was identical to that of the previous day's visit. Children were informed that Harry wanted to show them his special birthday present again. The experimenter then uncovered the music box and told children "This is Harry's music box. Harry would really like to hear the music, but unfortunately he cannot remember how to turn on the music box." They were then asked by the experimenter "Can you help Harry turn on his music box?" If children required further prompting they were asked "Can you show Harry how to turn on the music box?" The experimenter waited until the child had performed two actions. The box was activated by the experimenter after the second action, regardless of whether or not the child had performed the correct action sequence. If children performed only one action initially, the experimenter prompted them further by saying, "Is there anything else you can do to turn on the box?" If the child still failed to perform a second action the experimenter asked "Can you show me again how to turn on the box?" Any further action that they then performed immediately activated the music box. However, when coding the results, only the first action that these children performed was recorded.

At the end of the second session, parents/caregivers were fully debriefed, thanked and given £8 to cover their expenses. All test sessions were recorded on DVD. The first author scored all recordings coding the first two distinct actions that involved manipulating[4] the handles, the location of those actions and the order in which the actions were performed. A second independent rater, blind to the experimental hypothesis, coded a random selection of 28% of the videos. An inter-rater reliability analysis revealed a high consistency between raters: Cohen's Kappa overall = 0.93; for action = 0.91; for action order = 0.92; for location order = 0.93; for location = 0.93.

## Results

### *Performance*

The percentages of children passing the task (i.e., with location, order and action types all correct) within each age band and across the two conditions are shown in Table 4. These did not differ significantly between the two conditions (object- and viewer-centred), $\chi^2(1, N = 112) = 0$, $p = 1.00$.

**TABLE 4**
Percentage of children in each condition who passed the music box task (numbers by total in parentheses)

| *Age (months)* | *Object-centred* | *Viewer-centred* |
|---|---|---|
| 24–29 | 7 (1/14) | 0 (0/14) |
| 30–35 | 29 (4/14) | 29 (4/14) |
| 36–41 | 43 (6/14) | 71 (10/14) |
| 42–47 | 71 (10/14) | 50 (7/14) |
| All children | 38 (21/56) | 38 (21/56) |

As is evident from Table 4, there is a discontinuity in performance between the younger and the older two-year-olds. Only one younger two-year-old passed the task as compared with eight of the older two-year-olds. In fact, the single passing child was within a week of being two-and-a-half. A chi-square analysis revealed that the proportion of children passing differed significantly across the four age groups, $\chi^2(3, N = 112) = 25.75$, $p < 0 .01$. Applying Fisher's exact test, [5] it was found that the proportion of children passing the task was significantly greater in the older two-year-olds than in the younger two-year-olds ($p < 0 .05$). It also showed that the proportion of children passing in the younger three-year-old age band was significantly greater than in the older two-year-olds, $\chi^2(1, N = 56) = 4.67$, $p < 0 .05$. Finally, the proportion of children in the older three-year-old age band who passed the task was not significantly greater than the proportion passing in the younger three-year-old age band, $\chi^2(1, N = 56) = .07$, $p = 0.79$.

### *Comparing performance against chance*

Assessing whether correct recall of the event was superior to chance is problematic due to the difficulty of determining the a-priori probability that children would produce the correct actions by chance. However, we can ask whether performance was better than chance *given correct performance of the two actions*. Seventy-seven per cent of the children performed both actions correctly. The probability that children pass the

[4] Touching a handle without moving it was not coded as an action.

[5] Fisher's Exact Test was used rather than Chi as two of the four cells in the contingency table had an expected value of less than 5.

**TABLE 5**
Percentages of children recalling individual elements and element combinations at each age on the music box task

| | *What* | *What–When* | *What–Where* | *Where* | *Where–When* | *What–When–Where* |
|---|---|---|---|---|---|---|
| 2-year-olds | 66 | 39 | 20 | 27 | 23 | 16 |
| 3-year-olds | 86 | 64 | 63 | 80 | 77 | 59 |

task given recall of the correct actions is 1/32.[6] Binomial tests on the 77% of the children performing both actions revealed that the proportion of younger two-year-olds who passed the task given recall of the actions was no greater than chance ($p = 0.36$), the proportion of older two-year-olds who passed the task given recall of the actions was significantly greater than chance ($p < 0$ .01), the proportion of younger three-year-olds who passed the task given recall of the actions was significantly greater than chance ($p < 0$ .01), as was the proportion of the older three-year-olds ($p < 0.01$).

### *Applying the elemental model*

The percentage recall of the individual elements and the relevant bindings (order is relative to both location and action) are shown in Table 5. These are the data that went into the elemental model.

The elemental model was applied to the data in exactly the same way as it was in the WWW task of Experiment 1, with the only difference being that A for "action" replaces I for "icon" (see Appendix). As before, low expected values in some cells necessitated the amalgamation of data within a two-year-old and a three-year old band, rather than retaining the four 6-month age bands.

Figures 7 and 8 are histograms of the expected score distributions calculated in this way ("Expected") together with those for the range of scores actually obtained ("Observed") for both two-year-olds and three-year-olds. Among two-year-olds (Figure 7), there was a significant difference between Expected and Observed scores: $\chi^2(4, N = 56) = 9.63, p < 0$ .05. In order to compare the distribution of Expected and Observed scores for the three-year-olds (Figure 8), it was necessary to combine cell counts for recall scores of 0 and 1 to create a "1≤" cell. This was due to the low expected frequency count for scores of 0 and 1. There was

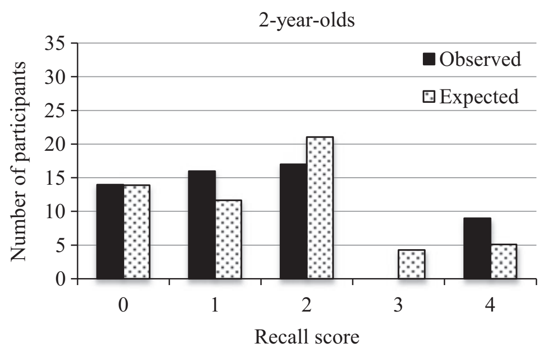


**Figure 7.** Observed scores against those expected on the elemental model for two-year-olds on the "music box" WWW task.

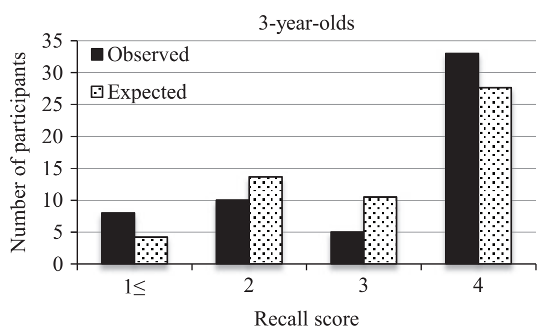


**Figure 8.** Observed scores against those expected on the elemental model for three-year-olds on the "music box" WWW task.

a significant difference between the Observed and Expected distribution for the three-year-olds (Figure 8), $\chi^2(3, N = 56) = 8.29, p < 0.05$. The AQ5 performance of both two- and three-year-olds was, then, inconsistent with the elemental model.

## Discussion

This study has shown that when the spatial information provided in the original demonstration of a deferred imitation task (with semantically arbitrary WWW content) can be coded with 3D, clearly allocentric information then there is

[6]Four locations acted on twice times 2 orders = 32.

evidence of configural recollection of the WWW elements at both ages 2 and 3. The low numbers of children scoring three points in this study (see Figures 7 and 8) is consistent with the idea that children were likely either to fail to recall W elements or recall all three of them: few children were "nearly there." Although there was only a modest difference in the degree of successful recollection between this task and the two WWW tasks used in Experiment 1, and no difference in the age at which superior-to-chance performance emerged, only in the music box study was there evidence of non-elemental, and thus configural, recollection.

In the light of our earlier discussion, a plausible explanation for this difference is that in the WWW task in Experiment 1 the spatial content was 2D, whereas in the Experiment 2 task the content was 3D and therefore naturally afforded allocentric coding. The interpretation is supported by the fact that the provision of egocentric cues in the second experiment (in the viewer-centred condition) did *not* improve performance.

It would not be appropriate, however, to claim from these data that two-year-old-children are generally capable of configural recollection in WWW tasks in which the spatial content can be coded allocentrically and the temporal content involves order information. This is because of the very low level of success found in children below two-and-a-half. That said, because the performance of children above this age tended to be at an above-chance level, it is fair to conclude that configural WWW binding can be seen to begin after two-and-a-half. This could be taken to mean that a minimal form of episodic memory begins at this age. Two-and-a-half is a plausible age for the onset of such a memorial capacity, given that after two-and-a-half may be when infantile amnesia begins to fade (Davis, Gross, & Hayne, 2008; Eacott & Crawley, 1998; though see Bruce et al., 2005; Wells, Morrison, & Conway, 2014 for later estimates).

## GENERAL DISCUSSION

One may conclude the following from these data. When only 2D, essentially egocentric, spatial cues are provided in the initial event (Experiment 1) two- to three-year-old children's deferred imitation recall is elemental, and putatively non-episodic. But when allocentric spatial information is afforded (Experiment 2), then two- to three-year-old children's memory is non-elemental and putatively "proto-episodic" (see The Present Empirical Strategy in the Context of Related Research Findings section). How can this difference be explained? First, we will consider a plausible neuropsychological explanation for the result. After this, we will resolve the seeming paradox that re-experiential memory is from a point-of-view and yet dependent upon allocentric coding. We then consider how these results can be placed in relation to what we already know about young children' s deferred imitation and WWW binding. Finally, we will consider the prospects for taking the temporal element in WWW memory to be simultaneity rather than order.

First, why did the difference between Experiment 1 and 2 emerge? The explanation may lie in hippocampal development. Not only is it universally accepted that the hippocampus plays a crucial role in episodic memory[7] and spatial coding, but there are good grounds for thinking that early episodic memory is essentially hippocampal rather than frontal (Newcombe et al., 2007; and see below). Moreover, as we have seen, Iordanova et al. (2011), in their work on WWW memory in the rat, report that such memories are disrupted by hippocampal lesions.

Crucially, the nature of this spatial coding in the hippocampus appears to be 3D/allocentric rather than egocentric. The co-discoverer of place cells in the rat hippocampus John O'Keefe (see O'Keefe & Nadel, 1978) has argued, from single-cell recording, that the spatial representation system in the rat hippocampus constitutes a perspective-independent mapping system with a layout-centred frame of reference (O'Keefe, 1990). Indeed, he has argued that this environmentally anchored coordinate system is a good candidate for being the physiological underpinning of Kant's spatial "a priori" (O'Keefe, 1993).

Moreover, that the hippocampal mode of spatial representation in humans is allocentric rather than egocentric is consistent with studies showing that individuals with early hippocampal damage are specifically impaired in spatial memory tasks in which there is a shifted viewpoint (necessitating the remapping of egocentric information) at retrieval and when the background scene changes in same-view conditions (King, Trinkler, Hartley,

[7] This is not to deny that the semantic binding is can also take place in the hippocampus (Manns, Hopkins, & Squire, 2003), a fact relevant to our What–What–What control task.

Vargha-Khadem, & Burgess, 2004). In an imaging study of the intact adult brain, Burgess, Maguire, and O'Keefe (2002) have shown that the right hippocampus is implicated in recalling locations in an environment, with the left area being implicated in episodic memory. In the latter review, and with regard to the question of landmark cues, the point is very clearly made that it is 3D landmarks that the hippocampus processes, not 2D ones.

Turning to development, it is known from imaging studies that hippocampal volume increases substantially during the first two years of life (Utsunomiya, Takana, Okazaki, & Mitsudome, 1999). On the behavioural side, studies of early episodic memory development by Newcombe and her colleagues have resulted in a variety of data suggesting that success on what they regard as hippocampally dependent tasks—tasks involving place learning—becomes possible around the second year of life (Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Sluzenski, Newcombe, & Satlow, 2004). As mentioned earlier, Newcombe et al. (2014) have shown that binding in memory what kind of toy to the box containing it and to the room in which the box was located is possible in the second year of life. This latter result will be discussed again below.

That said, it is necessary to insert caveats about how the current data support this interpretation. In the first place, as cautioned in the First Study, Spatial Content and the Elemental Model section, it is not impossible that the children in Experiment 1 were construing the corners as landmarks, despite their having no distinguishing perceptual features. Second, there are a number of respects in which the two procedures differed, in addition to one of them being 2D and affording egocentric coding and one being 3D and affording allocentric coding. For example, the semantic elements were different (icons versus actions), the semantic elements in the iPad task were constantly present, the music box procedure was narratively rich and the children had to be more active in performing on it. That said, features of this kind cannot naturally explain the qualitative differences between the two sets of data. An account in terms of allocenticity and hippocampal development is, however, satisfying. This is of course a matter for further research.

To come to the second issue (the "seeming paradox"), simply to say that the association between allocentric spatial coding and non-elemental, putatively episodic, recall is due to the fact that both kinds of processes are mediated by the hippocampus is to present a paradox. As was said initially when considering the "egocentric" reading of the Kantian spatial "a priori", both experience and re-experiential memory are "from a point of view," which would immediately suggest that it is body-centred information that is preserved in episodic memory. But this body-centred, perspectival information can represent, not merely bare egocentric relations of left/right, near/far, above/below, but also the knowledge that X was on my left/right etc. *by virtue of the fact that, in the past, I was bodily situated before an allocentrically codable layout,* in which some elements were positioned before me in such-and-such a way. To expand on this point, imagine a visitor to London standing looking down Kensington Road with the Albert Hall on her left and the Albert Memorial on her right. She episodically recalls this view some time later. One object is on her left and one is on her right, but within her episodic recollection of standing there, these egocentric relations are taken to be such because the Albert memorial is *in front of* the concert hall with her body between them. *The point-of-view is a function of where she was and what was before what*. So the paradox is resolved: recollection from an egocentric perspective can be grounded in allocentric coding because "A on the left of B" in her experience and re-experience is known to be due to the fact that her spatial position triangulated the two with B in front of A. Christoph Hoerl describes the significance of this matter thus: "the causal understanding involved in episodic memory consists in a grasp of certain spatiotemporal constraints on remembering, that is, of the fact that *we must have been around to witness an event before we can remember it*." (2001, p. 333; emphasis added).

Quite apart from these "theory-internal" issues, it is necessary to consider the relevance of these data to the current state of the evidence for young children's memory abilities as assessed by deferred imitation and other WWW procedures. This evidence was briefly reviewed in the Present Empirical Strategy in the Context of Related Research Findings section . First, it would be too restrictive to say that because the deferred imitation studies by Bauer, Meltzoff and others did not have an explicitly WWW structure that they could not have been tapping something close to re-experiential memory. Proto-episodic memory could hardly develop from a form of memory capacity that had no re-experiential format at all. Indeed, there is no compelling reason why toddlers, at least, should not credited with proto-episodic recollection. As Bauer (2013) points out, the phenomenon of infantile amnesia has encouraged us to think that “adults lacked memories from early in life because children failed to create them.” (Bauer, 2013, p. 515).

The question then becomes how one might employ a WWW procedure with children much younger than two-and-a-half years old. What is surely inadvisable is the use of arbitrary temporal orders, given the difficulty that younger children have with them (Bauer et al., 1995). One suggestion from securely within the present theoretical position is to use simultaneity rather than order as the When element (“Minimal” Episodic Memory in Animals and Children section ). As discussed, this has already been done within the rat literature (Eacott & Norman, 2004), given that Which-context (the background of the cage in this case) is something simultaneously present with the spatial and semantic elements. Moreover, as noted, Newcombe et al. (2014) have employed this What–Where–Which design with a search task in very young children. If indeed What–Where–Which is really What–Where–When (simultaneity), then we have a procedure that might be used with toddlers or even infants. In the two studies mentioned, simultaneity was also a spatial fact; but it need not be so. For example, simultaneity could be the co-occurrence of an object in a location with an auditory cue or some coloured illumination. This is a kind of temporal content worth exploring developmentally via deferred imitation in young children. It may reveal undreamed-of capacities.

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## APPENDIX

The elemental model assumes that recall of location and recall of icon (i.e., recalling that different ones must be moved each time) are independent of one another and that recall of location order given recall of location is independent of icon, that recall of icon order given recall of icon is independent of location and that location order given location is independent of action order given action. If we know the probability of getting location correct $P(\mathrm{L})$, the probability of getting location order correct given location $P(\mathrm{LO/L})$, the probability of getting icon correct $P(\mathrm{I})$ and the probability of getting icon order correct given icon $P(\mathrm{IO/I})$ then we can calculate an expected distribution of scores from 0 to 4 using the following equations.

The expected probability of scoring 0 is the product of the probability of getting location incorrect and the probability of getting icon incorrect (using the same one twice). It is given by the following equation: $(1–P(\mathrm{L})).(1–P(\mathrm{I}))$.

The expected probability of scoring 1 is equal to the probability of getting location correct, location order incorrect and icon incorrect added to the probability of getting icon correct, icon order incorrect and location incorrect. It is given by the following equation: $(P(\mathrm{L}).\ (1–P(\mathrm{LO/L}).\ (1–P(\mathrm{I})) + (P(\mathrm{I}).\ (1–P(\mathrm{IO/I}).\ (1–P(\mathrm{L}))$.

The expected probability of scoring two points is equal to the probability of getting location and location order correct but getting icon incorrect, added to the probability of getting icon and icon order correct but getting location incorrect added to the probability of getting location correct and icon correct but getting location order incorrect and icon order incorrect. It is given by the following equation: $(P(\mathrm{L}).\ P(\mathrm{LO/L}).\ (1–P(\mathrm{I})) + (P(\mathrm{I}).\ P(\mathrm{IO/I}).\ (1–P(\mathrm{L})) + (P(\mathrm{L}).\ P(\mathrm{I}).\ (1–P(\mathrm{LO/L}).\ (1–P(\mathrm{IO/I}))$.

The expected probability of scoring three points is equal to the probability of getting location and icon correct and getting location order correct but getting icon order incorrect added to the probability of getting location and icon correct and getting location order incorrect but getting icon order correct. It is given by the following equation: $(P(\mathrm{L}).\ P(\mathrm{I}).\ P(\mathrm{LO/L}).\ (1–P(\mathrm{IO/I})) + (P(\mathrm{L}).\ P(\mathrm{I}).\ (1–P(\mathrm{LO/L}).\ (P(\mathrm{IO/I}))$.

Finally, the expected probability of scoring four points is equal to the probability of getting location correct and icon correct and location order correct and icon order correct. It is given by the following equation: $P(\mathrm{L}).\ P(\mathrm{I}).\ P(\mathrm{LO/L}).\ P(\mathrm{IO/I})$.