It is about time:

conceptual and experimental evaluation of the temporal cognitive mechanisms in Mental Time Travel

Gema Martin-Ordas

University of Stirling

Author note

Gema Martin-Ordas, Department of Psychology, University of Stirling, UK. Correspondence concerning this article should be addressed to Gema Martin-Ordas, Division of Psychology, University of Stirling, Stirling, United Kingdom.

Contact: gema.martin-ordas@stir.ac.uk

Abstract

Mental time travel is the ability that allows humans to mentally project themselves backwards in time to remember past events (i.e., episodic memory) or forwards in time to imagine future events (i.e., future thinking). Despite empirical evidence showing that animals might possess mental time travel abilities, some still claim that this ability is uniquely human. Recent debates have suggested that it is the temporal cognitive mechanism (i.e., ability to represent the sense of past and future) that makes mental time travel uniquely human. Advances in the field have been constrained by a lack of comparative data, methodological shortcomings that prevent meaningful comparisons, and a lack of clear conceptualizations of the temporal cognitive mechanism. Here I will present a comprehensive review into mental time travel in humans and animals—with a particular focus on great apes. I will examine three of the most prominent and influential theoretical models of human mental time travel. Drawing on these accounts, I suggest that a basic way of understanding time might be shared across species, however culture and language will play a critical role at shaping the way we elaborate mental representations about past and future events.

Keywords: mental time travel, great apes, time, evolution

Time is always moving forward. However, humans can remember past events (e.g., our last holiday), and imagine and plan for events that have not happened (e.g., our next job interview); that is, we can mentally travel back into our past (i.e., episodic memory) and our future (i.e., future thinking). A crucial feature of the ability to mentally travel backwards and forwards in time is the temporal mechanism—the experience of being aware of "… the temporal dimension of their own and others' existence…" –referred to as *chronosthesia* (Tulving, 2002; p. 313); that is, the ability to represent the sense of past and sense of the future. Mental time travel (henceforth MTT) has a significant impact on humans' ability to survive (e.g., identifying future threats, like global warming) and also accounts for fundamental aspects of human culture (e.g., morality, law, religion; Suddendorf & Corballis, 2007).

Are humans the only animal species that can mentally travel in time? Or do we share this capacity with other animals? Debates on this issue have mainly focused on whether animals possess the self-knowing (*autonoetic*) awareness that accompanies human recollection. This has led comparative research to a deadlock since it is *empirically intractable* if animals (and preverbal children) have this type of consciousness. The debate has recently been resumed by some arguing that it is the temporal cognitive mechanism of MTT that makes this ability uniquely human.

This present review will build upon this renewed approach to address the research questions concerning the uniqueness of MTT. Since some of the most controversial evidence for MTT has come from work with great apes, I will exclusively focus on the research carried out in our closest relatives and I will contrast it to the research conducted with humans. I first provide a general overview of what episodic memory and future thinking entail. Next, I review the research on MTT using non-verbal tasks in great apes and humans and I highlight the shortcomings of this research. Finally, I describe and provide a critical view of three theoretical models of human MTT that have directly dealt with the temporal cognitive mechanism of this ability. My ultimate goal is to show that comparative work on MTT must move away from the study of the *mental* aspect of this ability and, instead, focus on the *temporal* aspect of MTT.

1. Mental Time Travel: Episodic Memory and Future Thinking

In the study of memory, one of the most influential distinctions is between semantic and episodic memory (Tulving, 1972). Semantic memory was originally defined as our database of knowledge about the world (e.g., winters in Scotland are cold). In contrast, episodic memory was considered to receive and store information about temporally structured events,

along with the spatiotemporal relations between them (i.e., what happened, where, and when). Tulving gradually (Tulving, 1983, 2005) refined the defining contents of these memory systems, referring to episodic memory as a memory system allowing us *mental travel* backwards in time, implying a sense of past.

Tulving (2005) also argued that the adaptive function of episodic memory lies, not only in the keeping of records of the past, but in what it can offer to present and future decision making for humans and other animal species (Suddendorf & Corballis, 2007). Future thinking is a highly adaptive cognitive ability that allows individuals to mentally pre-experience future events and needs and act in the present to address them (Atance & O'Neill, 2001; Szpunar, 2010). Ample evidence from both psychology and neuroscience indeed shows that the episodic system is involved both in re-constructing past events and thinking about the future (Suddendorf, 2010). During the past two decades, there has been an extraordinary increase in the number of studies on MTT in humans (e.g., Atance, 2015; Schacter, Benoit & Szpunar, 2017; Zhang, M. & Hudson, 2018 for reviews). There has also been a push to develop methods to test MTT in young children because, for example, thinking about the future is argued to be a fundamental component of planning, delaying gratification, and anticipating the future consequences of one's behaviour (e.g., Atance, 2015; Hudson, Mayhew & Prabhakar, 2011). Studying its development is also crucial for refining theories about the defining features of episodic cognition. This research has shown that the ability to recall past events and think about future events improves substantially between ages 3 and 5 (e.g., Hudson et al., 2011; McCormack & Atance, 2011).

However, a comprehensive understanding of MTT can only be achieved by investigating whether and to what degree humans and non-human animals (henceforth animals) possess such capacity. Comparative studies are informative in this regard. In the last 20 years, comparative psychologists have provided empirical evidence that other animals besides humans remember the content of past events (i.e., what, where and when something happened) and possess some type of future thinking abilities (e.g., Templer & Hampton, 2013). These findings have been the focus of arduous debates—with some claiming that MTT abilities in animals are similar to those in humans (e.g., Clayton, Bussey & Dickinson, 2003; Osvath & Martin-Ordas, 2014) and others arguing that even the strongest pieces evidence of MTT animals can be acknowledged to be no more than (associative) learning achievements (e.g., Suddendorf & Coballis, 2007; Hampton, 2018). In the next section, I describe the main non-verbal approaches developed to test episodic memory and future thinking in animals. I also describe how these paradigms have been adapted to test MTT in humans.

2. Main Non-Verbal Experimental Approaches to the study of Mental Time Travel

2.1. Episodic Memory: The What, Where and When Paradigm

2.1.1. Great apes

Based on Tulving's (1972) original definition of episodic memory, Clayton et al. (2003) developed the behavioural criteria for studying episodic memory in animals. In their experiment (Clayton & Dickinson, 1998), scrub-jays (*Aphelocoma californica*) cached 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 "what" (i.e., type of food), "where" (i.e., its location), and "when" (i.e., how long ago).

Martin-Ordas, Haun, Colmenares and Call (2010) adapted the what, where and when paradigm (hereafter WWW paradigm) for use with great apes. In their first experiment, Martin-Ordas et al. (2010) tested whether chimpanzees, orangutans and bonobos could remember the location of their preferred but perishable food (i.e., frozen juice) and of their less preferred but non-perishable food (i.e., grapes) after 5 min and 1 hour. The results showed that great apes were able to remember what, where and when by selectively choosing the perishable food after 5 min and non-perishable food after 1 hour. Additionally, Martin-Ordas and colleagues also showed that the what, where and when components were integrated into a single memory. In their experiment, subjects witnessed two different baiting events—each baiting event involved hiding frozen juice and a grape- separated by 1 hour. Five minutes after the second baiting event, apes could choose two times in succession—one choice per table. If apes encoded the baiting events into integrated what–where–when structures, they should preferentially choose the frozen juice in the table baited last but the grape in the table baited first. This is what Martin-Ordas and colleagues found. These results suggest that great apes could flexibly distinguish between two similar baiting events (see Dekleva, Defour, de Vries, Spruijt & Sterck, 2011 for negative results).

A critical concern with the WWW paradigm is that it does not assess the autonoetic consciousness component of episodic memory. For this reason, Clayton and Dickinson (1998) refer to them as "episodic-like memories." Importantly, animals' performance in this paradigm has been interpreted as drawing on semantic memory—rather than episodic memory. This is because one could remember what, where and when something happened without having a personal recollection a past event (e.g., remembering when I was born; Suddendorf and Busby, 2003; however see Martin-Ordas, Atance & Caza (2014) for a review on episodic and semantic memory and the thin line that separates these memories).

2.1.2. Humans

Studies have shown that in WWW paradigms human adults recall *what*, *where*, and *when* something happened (e.g., Cheke & Clayton, 2013; Craig et al., 2016; Easton, Webster, & Eacott, 2012; Holland & Smulders, 2011; Mazurek, Bhoopathy, Read, Gallagher, & Smulders, 2015; Pause, Jungbluth, Adolph, Pietrowsky, & Dere, 2010; Plancher, Gyselinck, & Piolino, 2010). In these studies, participants are usually asked to recall, for example, in which room (e.g., Craig et al., 2016; Holland & Smulders, 2011) or quadrant of a computer screen (Pause et al., 2010) (i.e., "where") and in which order (i.e., "when") coins (e.g., Craig et al., 2016; Holland & Smulders, 2011) or visual stimuli (Pause et al., 2010) (i.e., "what") were hidden or seen before. Similarly, Hayne and Imuta (2011) used a hide-and-seek procedure with 3- and 4-year-olds to test at what age children remember *what* (i.e., 3 different toys), *where* (i.e., 3 rooms in which the toys were hidden) and *when* (i.e., order in which the 3 rooms were visited when hiding the toys). Their findings showed that whereas 4-year-olds succeeded at recalling *what*, *where* and *when*, 3-year-olds struggled to remember the order in which the rooms where visited when hiding the toys (i.e., *when* component). Crucially, successful performance in these tasks has been interpreted as evidence that the WWW paradigms rely on episodic memory. Since participants in these tasks can verbally report their episodic experience together with their memory for the *what*, *where* and *when*, the inference is that animals might also be relying on these episodic recollections in the WWW paradigms.

2.2. Future Thinking: The Spoon Test

2.2.1. Great apes

The experimental approach to study future thinking across different species has mainly relied on the use of the *Spoon test* (Tulving, 2005). This test is based on the following scenario: A young girl dreams that she is at a party where all the guests are being served chocolate pudding. To eat the pudding, the young girl needs a spoon, but she does not have one. That night, she falls asleep while holding a spoon. Bringing the spoon represents an instance of future thinking because it implies *envisioning* a need that will occur in the *future*.

Based on the spoon-test paradigm, Mulcahy and Call (2006) presented orangutans and bonobos with an out-of-reach reward and with a set of useful and useless tools, which they could take into a waiting room. To obtain the reward, subjects had to return to the room where the out-of-reach reward was placed, carrying the useful tool, either 1 or 24 hours after having seen the reward. Mulcahy and Call showed that great apes saved tools for the future. However, Suddendorf and colleagues (Suddendorf, 2006; Suddendorf & Corballis, 2007) suggested that an alternative explanation is that subjects experienced a desire for the reward throughout—

indicating that thinking about the future was not required to succeed in this task. In addition, Suddendorf and colleagues argued that simple associative learning could explain their results. This is because over the trials, subjects could have learned an association between the tool and the reward; therefore no foresight might have been involved in their decision to take and transport the tool.

Osvath and Osvath (2008) addressed some of the criticisms aimed at Mulcahy and Call's (2006) study. Osvath and Osvath (2008) also presented chimpanzees and orangutans with a tool-use task, in which the selection, saving, and transportation of a tool was required to succeed. Their findings showed (1) that apes disregarded an immediate small, but highly liked, reward in favour of the appropriate tool that would give access to the future larger reward; (2) that the functional tool was not selected merely on the basis of being an associatively learned stimulus, but rather on its functionality; and (3) that apes selected the correct tools, but this tools were never encountered before. Altogether they concluded that great apes were engaging in planning behaviors for the future by outcompeting current drives and mentally pre-experiencing an upcoming event. Importantly, Osvath and Osvath's results are very difficult to explain by appealing to associative learning mechanisms alone (see Suddendorf et al., 2009, for a critical review; see Osvath, 2010, for a response).

2.2.2. Humans

The Spoon test has also been successfully implemented in developmental studies. For example, Suddendorf and colleagues (2011) presented children with a locked box that had a triangular keyhole. In a different room and after 15 min children were told that they were going to go back to the first room. Then, children were asked to select one of four keys to take with them. Suddendorf et al. (2011) found that whereas 4-year-old children could successfully select the correct key to solve the future problem (e.g., unlock the box to obtain the sticker), 3-year-olds failed to do so (see Atance & Meltzoff, 2005; Atance, Low & Clayton, 2015; Atance & Sommerville, 2014; Redshaw & Suddendorf, 2013; Scarf, Gross, Colombo & Hayne, 2013; for similar results using the Spoon test). Using a similar paradigm, Scarf et al. (2013) showed that 3-year-olds were also successful at bringing a key back to a location where there was a locked treasure box—note that in this case successful performance was determined by the length of the delay between being presented with the problem and the object selection phase (see also Atance & Sommerville, 2014 for similar findings on how memory—rather than future thinking- seems to driving performance in the Spoon test paradigms).

Since then, several studies have used different variants of the Spoon test to assess future thinking in children (e.g., Atance & Sommerville, 2014; Cuevas, Rajan, Morasch, & Bell,

2015; Dickerson, Ainge, & Seed, 2018; Russell, Alexis, & Clayton, 2010). Overall, all these studies typically show an age-related improvement in the Spoon test between ages 3 to 5.

3. Key issues

3.1. Are the paradigms assessing the past and the future at all?

(i)   WWW paradigms. The temporal cognitive mechanism is not consistently addressed across the tasks designed to test the recollection of past events. For example, different authors have argued about the need to include (or not) temporal information when testing episodic memory. There is no doubt that temporal information helps to dissociate between two similar memories. However, when this information is not available, humans use contextual cues to differentiate between events (e.g., going to the same restaurant twice with a different friend; Friedman, 1993).

Accordingly, some authors have suggested that the concept of WWW should be broadened to test the recollection of contextual cues—so-called what-where-which paradigm (Eacott & Norman, 2004; Eacott & Gaffan, 2005; Eacott, Easton & Zinkivsky, 2005). Eacott and Norman (2004) and Eacott et al. (2005) developed an experimental paradigm to test if rats remember what happened, where, and in which context an event happened. The general procedure consisted of presenting rats with 2 novel objects placed in an E-shaped maze. In order to create two different contexts, the maze was covered either with a dark cloth or with a wire mesh. Importantly, the objects were placed in different positions in each of the two contexts and subjects could not see the objects from the entrance. Subjects were exposed to both contexts and were habituated to one of the two objects. Since rats have a natural preference for novel objects, authors expected rats to go to the area containing the non-habituated object. Rats remembered what was where in which context the objects were placed. Eacott and colleagues suggest that one of the strengths of their procedure is that it requires no training and, therefore, reduces potential confounds caused by reinforced learning (Eacott & Norman, 2004). Furthermore, the recollection of the combination of object, location and context is unexpected (Kouwenber et al., 2012). Thus, by using what-where-which rather than what-where-when, Eacott and colleagues seem to have demonstrated recollection of episodic (like) memory in rats (Eacott et al., 2005).

Cheke and Clayton (2010) have argued that "*replacing 'when' with 'which' gets closer to the phenomenology of human episodic memory—in which the 'when' element is often inaccurate or even absent but the rich context is central*" (page 917). However, as the authors also mention, even though "*episodic-like memory of an event need not entail the recollection of 'when' it occurred, this element is necessary to behaviourally confirm that memory is for a*

specific episode rather than for timeless facts about the spaces or objects involved in that episode" (page 917-918).

(ii) **Spoon Tests.** One concern with the Spoon test methodologies is the extent to which individuals need to think about a *future event* to make a successful choice. In these tasks, selecting the correct item may only indicate that children know that, for example, the key is useful for unlocking the box *now* without having to represent its use in a future event (Hudson et al., 2011; McCormack & Hoerl, 2011; Martin-Ordas, 2018). This is because the correct choice for the future is the same as for the present moment. This possibility has been addressed in a recent study in which a *two-step* "spoon test" was developed (Martin-Ordas, 2018). In this task, children had to think about the order in which two events could happen in the future. Specifically, to secure a future need (e.g., play with a marble run game), children *first* had to obtain a key that allowed them *next* to access the marbles. By the age of 4 children selected the key; however, it is only by the age of 5 that children selected the key *and* reasoned about the temporal sequence of future events (i.e., they indicated the correct order in which they had to visit the rooms so they could obtain the marbles to then play with them in the marble run). These findings suggest that by asking children to reason about event order they could well be thinking about the future and that item-choice measures alone—as the ones in the Spoon test-might not involve future thinking.

In addition, recent studies have highlighted that performance in the Spoon test is drastically affected when children are asked to spontaneously generate the solution to a problem rather than selecting a tool from a number of options (e.g., Moffett, Moll, & Fitzgibbon 2018; Atance et al. 2019)—also questioning the idea Spoon tests involve thinking about a future event. The results of these studies indicate that it is only by the age of 5 that children consider and start to generate the solutions for a future problem[*]. Also relevant for the

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[*] Along the same lines, in the two-step Spoon test, Martin-Ordas (unpublished data) found similar results. In this task, 3-, 4- and 5-year olds were asked to select a tool (e.g., a key to unlock the box with the marbles) and put it inside a bag for a future use (e.g., play with a marble run). The delay between experiencing the problem and allowing children to use the tool was 15 min. After the delay, the experimenter asked children *"Are you ready to come upstairs* [i.e., where the problem had previously been presented] *with me?"* If the child did not spontaneously remember to grab the bag with the tool, E said *"Is there anything you need to bring upstairs with you?"* The results showed that only 14% of the children *spontaneously* remembered to bring the bag back where the problem had previously been presented. Age had no effect on children's performance (χ^2=1.40, *df*=2, *p*=.495). In particular, 12% of 3-year olds, 13% of 4-year olds and 33% of 5-year olds remembered to spontaneously bring the bag. It is possible that to perform correctly in the spontaneous question, children not only had to generate the content of the rooms (i.e., marble run and marbles locked in a box) and the future goal (e.g., play with marble run) but also plan accordingly (e.g., bring the bag with the tool). This is in contrast to the prompted question, in which it could be argued that the experimenter directed children's attention to the bag with the tool; therefore, the planning aspect was given by the experimenter.

present review is Dickerson et al.'s (2018) study in which children, after seeing a specific problem, were presented with two high-value objects. Critically, whereas one of the objects could be used to solve the previously-observed problem, the other object could not. Children younger than 5 years of age failed to choose the correct object for the task. The study highlights the possibility that the associate strength of the objects is at play in the Spoon test tasks.

Recently, Redshaw and colleagues (2016) developed what they called "a minimalist" procedure to investigate great apes' and children's abilities to prepare for two mutually exclusive possibilities of a future event. Note that this is not a Spoon test paradigm, however the task was designed to test future thinking—as such this study is relevant for what it is being discussed in this Section and what it will be discussed in Section 4.2. In the task, a reward could fall from one of two possible openings in either an inverted Y-shaped tube (Redshaw & Suddendorf, 2016) or two parallel tubes (Suddendorf, Crimston & Redshaw, 2017). According to the authors, if children and apes could anticipate the *uncertainty of the future* outcomes, then they should place their hands to cover both openings to ensure they catch the reward. Their results showed that 4-year-olds covered both openings, whereas 2-year-olds and apes failed to do so. These findings raised the possibility that the ability to anticipate and plan for uncertain future outcomes is uniquely human. Lambert and Osvath (2018) argued that the paradigm developed by Redshaw and colleagues is not valid because when dropping two rewards—one in each tube- apes do not cover both openings. Thus, rather than not anticipating uncertain outcomes, apes might find it difficult to synchronize the actions of their hands or attend to two locations/tubes simultaneously (Lambert & Osvath, 2018). Note that this same explanation could account for younger children's performance in Redshaw and colleagues' task. However, follow-up studies showed that, at least, younger children performed much better when two balls were dropped at the same time and, therefore, with certain outcomes—indicating that young children's difficulties with the original task were related to the uncertainty of the outcome rather than to their ability to coordinate their hands (Redshaw, Leamy, Pincus, & Suddendorf, 2018; Suddendorf, Watson, Bogaart, & Redshaw, 2019).

An important issue with this paradigm is that it is not clear what it is truly measuring (e.g., McCormack & Hoerl, *accepted*); that is, subjects could cover both openings (a) because they *lack the knowledge* about where the ball is going to fall (i.e., uncertainty about the task), or (b) because they understand the *uncertainty of the future*. There is, however, a clear difference between the two options. Whereas the first one involves children not having the knowledge concerning the outcomes of the task (i.e., epistemic uncertainty), the second option implies understanding the availability of the these possible outcomes as happening in the

future. Thus, this minimalist paradigm fails to fulfil one of Suddenforf and Corballis' (2007) crucial criterion for a behaviour to be considered driven by future thinking (i.e., the temporal-spatial separation between the future event and the current problem) and it is also questionable the extent to which subjects' understanding and consideration of the future is needed in this task (see Redshaw & Suddendorf, 2020 for their take on these issues).

3.2. Different conceptualizations of the past and the future

As described above, the temporal cognitive mechanism is not consistently addressed in the tasks designed to test MTT in humans and great apes. Critically, when the temporal mechanism is addressed, the definition of the temporal mechanism differs across studies.

(i) WWW paradigms. Martin-Ordas, Atance, and Caza (2017) have suggested that there is a crucial difference between the WWW paradigms with humans and the ones with the animals: whereas in the former, the "when" component is defined as the "order" in which the hiding events took place, in the studies with the scrub-jays and great apes, it is defined as "how long ago" a past event took place. To overcome this issue Martin-Ordas et al. (2017) presented 3-, 4-, and 5-year-olds with a preferred food (i.e., popsicle) that was only edible after a short interval, and a less preferred food (i.e., raisins) that was edible after both short and long intervals. To make a successful choice, children had to remember "what" food item was hidden "where" as well as how much time had elapsed between the hiding of the two food items (i.e., "how long ago"). They only received 2 trials. Results showed that children chose their preferred food after the short intervals but, strikingly, did not select their less-preferred food after the long intervals. Consistent with previous findings, however, age-related changes in children's ability to remember "what" was hidden "where" were found. However, children struggled at estimating the duration of the trials (i.e., "how long ago")– a potential explanation for why they failed to make the correct choice in the WWW paradigm. A more controversial interpretation of Martin-Ordas et al.'s (2017) findings is that the WWW paradigm does not necessarily rely on episodic memory. When testing adults in the same paradigm, Martin-Ordas and Atance (2019) found that participants successfully took into account the retention interval when deciding whether to choose a non-perishable or perishable food - but only *after* having experienced the event once before. Therefore, these results question (1) the extent to which "how long ago" is a crucial component of episodic memory and (2) if it is a more primitive ability than the recollection of the order of the events, why then humans struggle to use this skill in WWW tasks.

(ii) Spoon Tests. A critical difference between most of the studies with children[†] and those with apes is that once children select the tool, they can use it immediately. In contrast, in the studies with animals the delay always happens after selecting the tool; that is, the tool is not for immediate use. Thus, it is unclear what the temporal parameters of the Spoon test are meant to be, since they have not been consistently implemented in the same way for children and animals. It also opens up the possibility that different cognitive abilities have been assessed in children and animals.

In the next section, I present an overview of the main theories that have provided a critical view on the comparative work by questioning the extent to which the temporal cognitive mechanism has been addressed in the paradigms described in Section 2.

4. Main theoretical criticisms

Since the publication of the classical WWW paradigm (Clayton & Dickinson, 1998), the field of MTT has been heavily divided between those who argue that animals' abilities to remember past events and think about the future are somehow similar to those in humans (e.g., Clayton et al, 2003; Osvath & Martin-Ordas, 2014) and those who think that these abilities are uniquely human (e.g., Tulving, 2005; Suddendorf & Corballis, 1997, 2007). At the heart of this debate was whether animals have the same type of consciousness (i.e., autonoetic awareness) as humans do—leading to a clash between the phenomenological criterion and the use of behavioural measures. These discussions seem to have reached an impasse since the issue of whether animals (and preverbal children) have this type of consciousness cannot be empirically assessed—research in adults mainly rely on language-based paradigms (e.g., word lists; Tulving, 1972; Hassabis, Kumaran, Vann & Maguire, 2007). Below the main 3 frameworks together with the alternative temporal cognitive mechanisms suggested by each of them are outlined.

4.1. The Stuck-in-Time hypothesis

Roberts (2002; Roberts & Feeney, 2009) argued that a prerequisite for an organism to travel back and forwards in time is to have a *concept of time*. Such concept involves an understanding of (1) past events as having occurred at different points over a duration of time

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[†] Note that Redshaw and Suddendorf (2013) did include a short delay (i.e., 5 min) between selecting the tool and returning to the room where the problem was placed. However, Scarf et al. (2014) have argued that given the short delay and the fact that going back to the problem-room was what children were to do next, children's choices could be explained in terms of their current motivational state (i.e., what they want right now rather than what they will want in the future). Another exception is Martin-Ordas' two-step Spoon Test in which children could either select the tool before a delay of 15 min or after the delay. However, the results showed that children's performance was not affected by "when" they could make their choices.

and (2) future events as events that will occur at different points over a duration of time. This is different from being able to keep track of time (Thorpe & Wilkie, 2006), time intervals (Roberts, 1981) or anticipate the outcomes of certain responses (Reynolds, 1968)—in fact, circadian cycles, internal accumulators of neural pulses or learning/semantic knowledge can account for animals' behaviour in these studies.

When it comes to the WWW paradigm, Roberts (2002) points out that performance in this paradigm has not been systematically interpreted as being driven by a single mechanism. For example, some studies describe animals as remembering "how long ago" between hiding food and retrieving it (Martin-Ordas et al., 2010), others as "when" the food was hidden (Griffiths, Dickinson & Clayton, 1999) or as time elapsed since hiding the food (Clayton, Yu & Dickinson, 2001; Martin-Ordas et al., 2010). Roberts and colleagues (Roberts & Feeney, 2009; Roberts, Feeney, MacPherson, Petter, McMillan & Musolino, 2008) argue that the cognitive mechanisms underlying these types of memory are different: whereas memory for "when" involves a temporal dimension in which past events can be placed (i.e., episodic memory), memory for "how long ago" implies keeping track of temporal distance between events[47]—and, consequently, not episodic memory. Thus, under the Stuck-in-Time hypothesis the WWW paradigm is not necessarily a test of episodic memory because the "when" component is assessed as "how long ago." In order to overcome this issue, Roberts and colleagues (2008) developed a test in which subjects—in this case, rats- could use different temporal cues to find food: "when" (e.g., the time of the day in which an event occurred), "how long ago" (i.e., time elapsed between events) or both "when+how long ago." Rats were only able to use "how long ago" cues—suggesting that they can solve the WWW task by keeping track of time rather than by recollecting past events. Crucially, this study opens up the possibility that performance in the WWW paradigm does not require the same temporal cognitive mechanism than humans use when recollecting past events (Suddendorf & Corballis, 2007; Martin-Ordas et al., 2017; Martin-Ordas & Atance, 2019).

The Stuck-in-Time hypothesis also applies to future thinking. In fact, Roberts and Feeney (2010) argued that, similar to the WWW paradigm, alternative explanations (e.g., species predispositions) can account for animals' performance in the Spoon test. This is because this paradigm does not include a temporal mechanism that allows assessing whether animals can anticipate *when*—within a temporal framework- an event will happen. Thus, Roberts and Feeney (2010) claim that "*anticipation of the most proximate event in a sequence of future events*" (p. 52) is essential for demonstrating future planning. Osvath, Raby and Clayton (2010) critically responded to Roberts and Feeney's (2010) suggestion by arguing that

"a sense of past and future is regarded as a defining factor of MTT, [but] the precise time sequencing [...] is not" (p. 51). As yet, however, the question of whether animals can think about future events in a temporal framework that involves sequencing a series of events still remains open.

4.2. Metarepresentational approach

Redshaw (2014; see also Suddendorf 1999; Suddendorf & Corballis, 2007) argues that a crucial component of MTT is *metarepresentation* because it allows an organism to *"represent the nature of the relationship between current reality and alternative representations of reality"* (Redshaw, 2014; p. 1). As such, metarepresentational abilities allow an organism to represent the past and the future in relation to a representation of the current moment as well as *to reflect on and evaluate representations of future events "according to the particular features of future representations"* (Redshaw, 2014; p. 521); that is, an organism forming a mental representation of a future event should know that the representation of the future event could be wrong, and consequently, that the future event could have different alternative outcomes.

Under the Metarepresentational account, animals and very young children might only be able of *uncontextualized mental representations* of past and future events (i.e., mental *space* travel). These representations are integrated by components of different memories, but in these cases the organism will fail (1) to establish a relation between them and the current reality and, consequently, (2) to embed these representations in a temporal context. Redshaw (2014) suggests that in the Spoon test subjects could have selected the correct tool without having any mental representation of the future event and, thus, without establishing the relation between the representation of the present moment and the representation of the future moment. Similarly, performance in the WWW task could also be described as being guided by *uncontextualized* mental representations. In both tasks, a cue (e.g., tools) triggers the representation of a past event (e.g., having seen/used the correct tool before)—which facilitates the correct response (e.g., selecting the correct tool). Thus, animals cannot locate past or future events in a temporal context because they lack the metarepresentational abilities that would allow them to do so. As Hoerl and McCormack (2019) suggest, in Redshaw's view animals *"can mentally meander through time even if they have no idea where in time their meandering takes them"* (page 9).

Recently, Redshaw and Suddendorf (2020; see also Redshaw, Bulley & Suddendorf, 2019) have elaborated on this framework and suggested that *recursion* allows humans to *embed* different levels of mental representations when thinking about the past or the future [i.e., a

representation "with a particular temporal orientation (forward-looking or backward-looking) is represented as being located within another representational perspective with its own temporal orientation", Redshaw & Suddendorf, 2020; p. 53]. They suggest a multilevel system varying in the degree of recursivity required to elaborate the temporal representation (e.g., imagining a future event in which we remember a past event that in the past had different future outcomes). In humans, this milestone is achieved after the development of the ability to prepare for mutually exclusive possibilities. Despite the level of complexity added to their framework, it is still unclear how temporal reasoning becomes critical for a creature to mentally travel in time. If we were to take their own example—putting away a second bottle of wine to prevent a hangover tomorrow- it is not clear why metarepresentation is required to make a decision (i.e., to not drink the second bottle) and, therefore, why making that decision cannot be based on an *uncontextualized* mental representation. Could not I just *know* that too much alcohol *causes* hangover? The question is, then, whether a simplified system would suffice to make these decisions and when/if recursion and meta-representational abilities are critical for MTT.

4.3. Dual System: temporal updating and temporal reasoning

Hoerl and McCormack's (2019) approach differentiates between two systems: *the temporal updating system* and *the temporal reasoning system*. The former is considered to represent objects as they are in their context (e.g., spatial location). When the objects change over time, this new information will be updated into the previous representation of the environment. Thus, in the temporal updating system—rather than representing that objects are different from what they were before- representations are simply amended/updated with the new information. As Hoerl and McCormack (2019) point out "*the temporal updating system operates with a model of the world that concerns the world only ever as it is at present*" (p. 2). However, the organism does need to *maintain the information over time* even when such information—about objects or locations- is not within perceptual scope. Single-trial learning, keeping track of elapsed time between events, sequential learning and anticipation are behaviours that can be performed by an organism with a temporal updating system.

In contrast, the temporal reasoning system allows an organism to represent points in time (e.g., before-after relationships). These representations contain information about the current state of the world and from other temporal dimensions (e.g., past events). Consequently, the temporal reasoning system not only supports the representation of temporal order representations between events happening at different times but also the representations of the events in a temporal framework (e.g., tense)—past, present and future. Thus, the crucial

difference between the temporal updating system and the temporal reasoning system is "*concerned with what a creature can represent—i.e., whether or not its model of the world contains a temporal dimension*" (p. 4). Hoerl and McCormack (2019) argue that representing the temporal aspect of the world is different from being sensitive to it.

The Dual System approach has received important attention from a developmental approach. Research has shown that children's ability to use the recalled temporal information in past-oriented tasks seems to emerge only by age 5 (e.g., Hoerl & McCormack, 2011; McCormack & Hoerl, 2005, 2007; McColgan & McCormack, 2008; Povinelli, 2001). For example, McCormack and Hoerl (2007) presented 4- and 5-year olds with an object-location task. Children were introduced to two dolls (e.g., John and Peter) that always performed actions (e.g., brush their hair) in a specific order (e.g., John first, Peter last). In this task, correctly identifying the location of the object (e.g., brush) depended on the recollection of the order in which the two dolls acted. McCormack and Hoerl (2007) found that it is only by the age of 5 that children can identify the location of the object. A similar developmental pattern has been found in relation to the use of temporal information in future-oriented tasks (e.g., Klahr & Robinson, 1981; McColgan & McCormack, 2008; McCormack & Atance, 2011; McCormack & Hanley, 2011; Prabhakar & Hudson 2014; Scholnick, Friedman, & Wallner-Allen, 1997; Welsh, 1991). For example, McColgan and McCormack (2008) assessed preschoolers' ability to reason about temporal order in a route-planning task. In this task, 3-, 4- and 5-year-olds were presented with a doll character that was planning to visit a toy zoo and wanted to take a picture of one of the animals (e.g., kangaroo). However, the doll did not have a bag to carry the camera. Children were asked to identify a location where the doll could leave the camera so she could pick it up before getting to the kangaroo location. McColgan and McCormack's (2008) showed that 5-year-olds identified the correct locations to leave the camera, but 3- and 4-year-olds failed to do so (see also McCormack & Hanley, 2011). Altogether these studies show that the ability to reason about before-and-after relationships in tasks that involve achieving immediate goals improves between ages 3 and 5.

Critically, under the Dual System approach, performance in the WWW tasks and Spoon tests is not supported by the temporal reasoning system but by the temporal updating system. In the case of the WWW paradigm, Hoerl and McCormack (2019) claim that there is no need to remember a past event itself (e.g., caching/hiding food), instead a timing mechanism that can alter the creature's representation of the world in a way that depends on how much time has elapsed since an event occurred (Hoerl & McCormack, 2011; McCormack, 2001). This mechanism is just a temporal sensitivity—which facilitates temporally appropriate updating of

the representation of the world. Similarly, performance in the Spoon-test tasks—both in children and animals- do not require the representation of a future event. When selecting a tool, subjects' representation of the task "*is represented as existing somewhere in the [subjects'] current spatial environment, and in this sense as potentially accessible. Together with the motivational state of desiring the contents of the apparatus, this seems sufficient to explain why the animals choose the tool*" (Hoerl & McCormack, 2019; p. 7). Thus, under this approach there is no evidence of MTT in animals.

5. Final remarks

The theoretical accounts described in Section 4 suggest that different (and mutually exclusive) temporal mechanisms underlie MTT. What all three accounts agree on is that, so far, MTT has not been demonstrated in animals and that addressing its temporal cognitive mechanism is a crucial exercise if we are to understand the evolution and development of MTT. Critically, it is also unknown whether MTT is possible with more than one temporal cognitive mechanism and whether these temporal mechanisms differ (or not) between episodic memory and future thinking. Thus, for a cognitive skill, Mental *Time* Travel, that surely involves a conception of the past and the future—and, consequently, a temporal mechanism that allows having an understanding of what the past and future might entail- research on its temporal aspect is still in its infancy (e.g., Zhan & Hudson, 2018 for a similar view).

In addition, our current understanding of MTT is mostly based on studies carried out in different animal groups (e.g., great apes, corvids). However, comparative studies in which different species are tested under similar circumstances using the same experimental paradigms are mostly lacking. As mentioned in Section 3, there are also a number of methodological shortcomings (e.g., different temporal cognitive mechanisms tested across species and paradigms) in the paradigms developed to test MTT. This together with the use of different experimental paradigms and the lack of comparative and comparable data hinder our understanding of the phylogeny and ontogeny of MTT and its underlying temporal mechanisms.

To move forward the field of MTT it is necessary to address the above-mentioned methodological and theoretical considerations. Developing experimental situations that allow us to clearly contrast different temporal mechanisms could be used as an starting point for

investigating this issue both from a developmental and comparative approach[‡]. As it currently stands, performance in the WWW and Spoon Test paradigms has been interpreted as not involving an understanding of past and the future. However the alternative explanation is also possible; that is, performance could well be driven by temporal reasoning skills (Hoerl & McCormack, 2019) or even by metarepresentational abilities (Redshaw, 2014). But the currently methodology does not allow to differentiate between these explanations: the behavioural outcome is the same (e.g., take the tool) regardless of the temporal mechanism that is at play. In the absence of paradigms with which to differentiate them, the differences between human and animals may still be based mechanisms postulated in post-hoc explanations (e.g., Hoerl & McCormack, 2019). Even if it were to be true that what differentiates human's from other animals' MTT abilities is the temporal cognitive mechanism (in whichever form), one would still need to explain how this (probably more elaborated) ability might have evolved. Whereas Redshaw (2014) and Roberts (2004) propose a single mechanism that makes MTT unique to humans (i.e., metarepresentation, "when" within a temporal framework), Hoerl & McCormack (2019) argue that animals are stuck with a more primitive mechanism that has to constantly be updated to keep up with the changes in the environment. But why would animals *only* have a temporal updating system—if so, all animals?- and humans would have a co-existing temporal updating system *and* a temporal reasoning system? What would the evolutionary pressures be for a system to develop two different temporal mechanisms?

Recently, Moore (*under review*) has put forward a cultural theory for the development and evolution of theory of mind (i.e., mind-modelling). In Moore's view, humans share with our closest relatives basic socio-cognitive skills that allow to track others' goal-directed behaviours. Critically, it is the cultural evolution of linguistic tools that has favoured the development of different models to describe mental states—through evolution the least expressive tools progressively would have disappeared. Thus, linguistic tools would have caused differences in the representational complexity of others' goal-directed behaviours between humans and animals. In addition, differences across cultures would arise in the way that these mental states are described (e.g., larger set of linguistic tools would allow the expression of finer differentiations between epistemic and conative states).

[‡] Note that Roberts (2002; Roberts & Feeney, 2009) has put forward two different experimental paradigms that could be used to test the concept of time (i.e., when) in humans and animals. Likewise, Hoerl & McCormack (2019) have suggested that Martin-Ordas's (2018) two-step Spoon task could be adapted for use with animals in order to test the temporal reasoning system.

Moore's view can easily be adapted to the issues discussed here. It is possible to argue that humans also share with other animals (e.g., great apes) basic cognitive abilities that allow them to represent the spatio-temporal content of previous or future events (e.g., Campbell 2006; Keven, 2016, 2019). Such basic temporal abilities might, for instance, be limited by the temporal proximity of the events—in the absence of cultural devices, such as calendars, clocks, timelines, it could be a struggle to represent a *distant past* or a *distant future* (see also Osvath & Martin-Ordas, 2014). In this sense, comparing great apes with Western humans could be confounding research on MTT. While the latter populations might be able to imagine what they will be doing in 10 years (e.g., buying a house), the former might only be able to foresee a closer future (e.g., where to build the nest tonight). Conducting studies in human populations with no access or with different levels of access to devices that allow keeping track of time might shed light on the extent to which being surrounded by and using such devices affect our future thinking abilities.

Under this *cultural* account, it would also be conceivable that *cultural practices* played a critical role in the evolution of different ways to think about time. For example, Woodburn (1982) described mobile, egalitarian huntergatherer groups (e.g., Aka group living in Central African Republic) as "immediate- return" societies, and sedentary, "complex" hunter-gatherers (like those who lived along the northwestern coast of the United States), as well as farmers, as "delayed return" societies. Whereas the delayed- return societies are based on systems in which individuals wait, for example, up to 6 months for a return of an asset, in immediate return societies the return of the investment takes place almost immediately after the action (e.g., hunting). The cognitive consequences of living in a society in which one is always looking for food to eat within the next hours/ days, as opposed to a society in which one is planning which crop to plant next year, might be tremendous on MTT abilities—in particular on the temporal cognitive mechanisms driving MTT. If these practices affect the way humans think about the future, then we might be doing a feeble favour to the field of comparative psychology by not addressing the (possible) wide variety of temporal mechanisms across different (human) populations.

Finally, and similar to Moore's account, the variability reported on temporal representations and temporal understanding in humans could have also resulted from cultural *tools* (e.g., cultural conventions, language; for a review Bender & Beller, 2014). Under this approach it would then be expected to find variation in the way, for example, time is described across different populations. We know that when speaking about time, people tend to do so using vocabulary from the spatial domain—this is because time is an abstract concept and we

make use of (mostly) spatial metaphors to conceptualize it (Lakoff & Johnson, 1980). For example, in Spanish language the past is placed behind the speaker (e.g., the worst is behind us) and the future in front (e.g., the best is ahead of us; Boroditsky, 2011). In contrast, in Aymara the past is described as being in front of the speaker and the future as being behind (Núñez & Sweetser, 2003). In addition to express two different ways in which the past and the future can be described, this example also highlights cultural differences in the way we do so. Thus, it is arguable that language could shape the way we think about time (and perhaps enable different forms of temporal cognitive mechanisms; see Everett 2017 for a similar argument on the evolution of number cognition).

Altogether, one, then, could argue that *complexity* and *variation* will come from the different ways in which culture (e.g., cultural practices, cultural constructions) and language shape our cognitive tools to reason about time. As a consequence, there could be uniquely human forms of temporal cognitive mechanisms—developed through language- that would facilitate thinking and reasoning about past or future events. Then, just as argued by Moore (*under review*), these cultural tools might have allowed us to extent our MTT abilities beyond those of other animal species.

In closing, different frameworks have suggested different temporal mechanisms that are play in MTT. Whether MTT is possible with more than one mechanism and whether differences across species exist in this regard is still an open question. If humans and animals shared a basic temporal cognitive mechanism and cultural tools and language are responsible for the complexity in which humans think about time, then comparative *and* cross-cultural research would be critical to have a comprehensive understanding of what MTT entails.

6. Conclusions

The present review was motivated by the main question of the role that the understanding of time plays in the development and evolution of episodic memory and future thinking. I argue that addressing this issue will shed light on whether MTT is uniquely human, and whether species differences are related to the temporal cognitive mechanism guiding human and animals' recollections and decisions about the future. I have also described 3 theoretical models—each of them suggesting different temporal cognitive mechanisms that play a role in MTT- as being critical models since they have all reinterpreted the animal work and argued that MTT is uniquely human. The three theoretical accounts described above claim that MTT is uniquely human because the cognitive mechanisms required to represent events in time emerge late in ontogeny and are lacking in other animals. I suggest that a basic way of

understanding time might be shared across species, however culture and language will play a critical role at shaping the way we elaborate mental representations about past and future events.

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