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# Disambiguating past events: Accurate source memory for time and context depends on different retrieval processes

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ABSTRACT

Current animal models of episodic memory are usually based on demonstrating integrated memory for what happened, where it happened, and when an event took place. These models aim to capture the testable features of the definition of human episodic memory which stresses the temporal component of the memory as a unique piece of source information that allows us to disambiguate one memory from another. Recently though, it has been suggested that a more accurate model of human episodic memory would include contextual rather than temporal source information, as humans' memory for time is relatively poor. Here, two experiments were carried out investigating human memory for temporal and contextual source information, along with the underlying dual process retrieval processes, using an immersive virtual environment paired with a 'Remember-Know' memory task. Experiment 1 ($n = 28$) showed that contextual information could only be retrieved accurately using *recollection*, while temporal information could be retrieved using either *recollection* or *familiarity*. Experiment 2 ($n = 24$), which used a more difficult task, resulting in reduced item recognition rates and therefore less potential for contamination by ceiling effects, replicated the pattern of results from Experiment 1. Dual process theory predicts that it should only be possible to retrieve source context from an event using recollection, and our results are consistent with this prediction. That temporal information can be retrieved using familiarity alone suggests that it may be incorrect to view temporal context as analogous to other typically used source contexts. This latter finding supports the alternative proposal that time since presentation may simply be reflected in the strength of memory trace at retrieval – a measure ideally suited to trace strength interrogation using familiarity, as is typically conceptualised within the dual process framework.



## 1. Introduction

The episodic memory system has been proposed to underpin our abilities to retrieve temporal–spatial relations between events, the subjective experience of reliving an event, autonoetic consciousness (Tulving, 1983), and mental time travel (Suddendorf & Busby, 2003). As conscious recollection and mental time travel are difficult to demonstrate in non-human animals, some researchers have suggested that episodic memory is a uniquely human cognitive ability (Suddendorf & Busby, 2003; Tulving, 2002). The utility of animal models is clear, as they allow for the study of episodic memory on a cellular and neural level currently not attainable in humans. Consequently a broad body of research has focused on the content, rather than the experience, of episodic memory to develop animal models (Clayton & Dickinson, 1998; Eacott & Easton, 2012) with almost exclusive emphasis placed on the integration of what happened, where it happened, and when (Clayton & Dickinson, 1998) or on which occasion it happened (Eacott & Easton, 2010; Eacott & Norman, 2004). According to these criteria, episodic memory and has been reported in rats (Eacott & Norman, 2004; Langston & Wood, 2010; Ergorul & Eichenbaum, 2004; Babb & Crystal, 2005, 2006; Kart-Teke, De Souza Silva, Huston, & Dere, 2006), mice (Davis, Easton, Eacott, & Gigg, 2013), birds (Clayton & Dickinson, 1998), chimpanzees (Martin-Ordas, Berntsen, & Call, 2013) and cuttlefish (Jozet-Alves, Bertin, & Clayton, 2013). In the absence of a demonstration of subjective experience to definitively show correspondence across animal and human memory systems, the memory capability demonstrated in the what-where-when (WWWhen) and what-where-which (WWWhich) memory paradigms has been termed episodic-like memory (Clayton & Dickinson, 1998).

The use of these episodic-like memory paradigms has led to further debate as to whether events are separated in memory using

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solely temporal information, as suggested by WWWhen memory (Babb & Crystal, 2005, 2006; Clayton & Dickinson, 1998; Ergorul & Eichenbaum, 2004; Roberts et al., 2008; Zhou & Crystal, 2009) or by the occasion in which they took place using either temporal or non-temporal identifiers, suggested by WWWhich memory (Eacott & Easton, 2010, 2012; Easton & Eacott, 2008). In spite of their central role within the widely used WWWhen paradigm, humans rarely use specific temporal cues when remembering episodes, relying instead on non-temporal information e.g. information about the weather, people who were there, and environmental context (Friedman, 1993; Wagenaar, 1986; Wells, Morrison, & Conway, 2014). Clearly, both temporal and non-temporal identifiers of an event can be thought of as sources that specify conditions under which memories were encoded (Johnson, Hashtroudi, & Lindsay, 1993), and can be interrogated using standard human memory paradigms.

To date, relatively few attempts have been made to assess the construct validity of the WWWhen or WWWhich paradigms by testing them within humans. Previous research with human participants has shown that while memory for both temporal and contextual information can be accurate (Easton, Webster, & Eacott, 2012; Holland & Smulders, 2011), the two models engage different retrieval processes within the dual process framework (Easton et al., 2012). Dual process theory states that memory can be retrieved using two processes, *recollection* and/or *familiarity* (for reviews, see Vilberg & Rugg, 2008, and Yonelinas, 2002). Within this framework, a memory supported by recollection is retrieved alongside its source, which unambiguously supports the recognition judgement. Familiarity, on the other hand, does not result in source retrieval—merely the awareness that the recognised stimulus relates to something from the past. These processes are often assessed using what is known as a Remember/Know (R/K) procedure in which participants are given a recognition memory test for items and/or sources seen during a Study Phase (c.f. Jacoby, 1991). For correctly identified items Remember and Know responses are given, where Remember corresponds to the process of recollection and Know to the process of familiarity (Dewhurst, Conway, & Brandt, 2009). Given this established operationalisation of the dual processes, the only retrieval process capable of supporting source information is recollection. Melding the two discussed sets of frameworks, it should therefore be expected that the temporal source component of WWWhen memories, and the contextual source component of WWWhich memories would both necessarily recruit recollection. This has led some researchers to suggest that recollection is truly episodic, while familiarity, which does not require the retrieval of an integrated memory of multiple features of an event, is not (Clayton & Dickinson, 1998; Easton et al., 2012).[1]

Easton et al. (2012) examined retrieval processes in human participants by projecting images of abstract figures on either a zebra or a checked background on to a large screen in a lecture theatre. They showed that accurate retrieval of contextual information was possible only using recollection. They also showed that, contrary to what would be expected within the dual process framework, memory for the order of stimulus presentation could be retrieved accurately using either recollection or familiarity. This finding questions the WWWhen model's assumptions of the integrity of temporal source cues to episodic memory, at least in humans. Moreover, it suggests that retrieval of temporal sources should not be treated as equivalent to contextual sources within the WWWhich model. There was an alternative explanation for the familiarity-supported temporal source component which is that familiarity judgments can be supported using memory strength (i.e. how little the encoding episode had decayed from memory indicating how recently it was encountered) rather than the retrieval of a true temporal source. We sought to conceptually replicate these findings using a longer sequence of time points both during study and test (6 time points compared to 2). This allowed us to examine the nature of the errors produced when attempting to use temporal source judgements. If temporal source questions were being solved using memory strength rather than retrieval of the precise temporal source then we would expect incorrect responses to cluster around the position of the correct response within the sequence of presentation at encoding. We additionally used an immersive testing environment to more closely match the conditions under which temporal source has been shown to be integral to episodic memory in animals.

To this end, we assessed time and context retrieval in an immersive virtual environment using an amended version of the standard Remember-Know procedure (Dewhurst et al., 2009; Donaldson, Mackenzie, & Underhill, 1996), with the only difference being that we asked for 'Familiar' instead of 'Know' responses in order to distinguish between the two familiarity processes suggested by Dewhurst et al. (2009). Over two experiments, we used a paradigm, in which participants moved through, and encountered a series of 3D objects in a virtual environment. We made the environment as immersive as possible by projecting it onto a wall in a darkened room, which was intended to give a strong sense of being present *within* the environment. During the study, participants encountered objects in different weather contexts and at different times (points in a sequence). Their memory for the items and their temporal or contextual sources was assessed alongside a judgement of recollective experience: Remember judgements indicating that participants could retrieve details surrounding the event when the object was presented, indicative of retrieval using recollection; and Familiar judgements indicating that participants only knew that an object had been seen without memory for surrounding information, indicative of retrieval using familiarity. Based on Easton et al. (2012) as well as a recent paper by Saive, Royet, Garcia, Thévenet, and Plailly (2015), we predicted that contextual source memory would be more accurate following self-reported engagement of recollection compared to familiarity, but that temporal source memory would be equally accurate across judgements that engaged recollection or familiarity.

## 2. Materials and methods

### 2.1. Experiment 1

#### 2.1.1. Virtual environment and stimuli

The virtual environment was created using the Valve Hammer World Editor (Valve Software, 2006), was projected onto a 375 cm × 250 cm screen at 1024 × 768 resolution, and was navigated through using a games console controller (Xbox 360, Microsoft). Participants were seated 420 cm from the wall. The virtual environment consisted of two rooms connected by a single doorway: a Start Room, where participants began each trial; and a Main Room where they encountered stimuli, (Fig. 1A). The Main Room had three windows facing a Courtyard. The Courtyard contained landmarks consisting of a sculpture, a car and a perimeter of buildings. Context was manipulated by altering the weather conditions in the Courtyard whilst keeping the landmarks constant. Six different contexts were used: sun, snow, lightning, rain, fog, and wind (Fig. 1B). Rain used the appearance and sound of rain hitting the

[1] It is worth noting that this episodic/non-episodic distinction revisits Tulving's (1983) original formulation of recollection as episodic and familiarity as semantic. Human memory researchers have since interpreted both processes as episodic within the dual process framework (e.g. since Yonelinas, 2001), making this an area in which there is little consensus across animal and human memory research.