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A novel experimental approach to episodic memory in humans based on the privileged access of odors to memories

Anne-Lise Saive*, Nadine Ravel, Marc Thévenet, Jean-Pierre Royet, Jane Plailly

Olfaction: From Coding to Memory Team, Lyon Neuroscience Research Center, CNRS UMR 5292, INSERM U1028, Université Lyon 1, 50 Avenue Tony Garnier, F-69366 Lyon cedex 07, France

HIGHLIGHTS

- We create a novel experimental approach to investigate episodic memory in humans.
- Incidental encoding and recall phases have been controlled.
- Complex olfactory episodes are close to real-life situations.
- Participants recall episodic memory in approximately half of the trials.
- Our protocol is adapted for the constraints of fMRI.

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ABSTRACT

Episodic memory is defined as the conscious recollection of a personal event (*What*) in its spatial (*Where*) and contextual (*Which context*) environment. In existing approaches, human episodic memory is either explored separately from real-life situations or is not fully controlled. In this study, we propose an intermediate approach, inspired by animal studies, that permits the control of the encoding and recall phases, while still being ecologically valid. As odors are known to be especially evocative reminders, we explored the memory of olfactory episodes. During trial-unique encoding, participants freely explored three episodes, one episode per day, each composed of three unnamable odors (*What*) that were positioned at specific locations on a board (*Where*) within a visual context (*Which context*). On the fourth day, both old and new odors were presented, and when an odor was recognized, the participants had to remember both its spatial location and the visual context in which it occurred. In Experiment 1, the participants were highly proficient at recognizing odors, and they recall the spatio-contextual environment associated with these odors in approximately half of the trials. To adapt the recall procedure to the constraints of fMRI, we conducted Experiment 2 demonstrating that trial repetition did not disturb the memory process. Thus, we first validated our protocol, which investigates the memory of olfactory episodes in a fully controlled way that is as close as possible to real-life situations. Then, we demonstrated the adaptability of our protocol for the future exploration of the neural networks implicated in episodic recall.

1. Introduction

Episodic memory was first characterized as the vivid and conscious recollection of a unique personal event and of the spatial and temporal contexts in which it occurred (Tulving, 1972). Thus, episodic memory was defined on the basis of different types of stored information: *What* happened, *Where* and *When*. Recently, Eacott and Easton (Eacott and Easton, 2010; Easton and Eacott, 2008) pointed out that humans have difficulty remembering the date or the temporal order of episodic events (Friedman, 2007). Because the temporal dimension of such events is often deduced from context (e.g., "It was snowing and I had this haircut, so it must have been Christmas, three years ago"), the authors noted that episodic memory is more of a "snapshot" of an episode, in which time forms a part of the context but is not essential. As a consequence, these authors defined episodic memory in terms of the dimensions "*What*, *Where*, and *Which occasion* or *Which context*," rather than in terms of "*What*, *Where*, and *When*."

Abbreviations: CR, correct rejection; FA, false alarm; WWW, an accurate recall of both the location and the context associated with a target odor; WWhere, an accurate recall of the location but not the context associated with a target odor; WWhich, an accurate recall of the context but not the location associated with a target odor; What, an inaccurate recall of both the location and the context associated with a target odor.

* Corresponding author. Tel.: +33 04 37 28 74 96; fax: +33 04 37 28 76 01.
E-mail address: anne-lise.saive@olfac.univ-lyon1.fr (A.-L. Saive).

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Table 1
List of odorants for Sets 1 and 2.

Set 1: Target odorants			Set 2: Distractor odorants		
Number	Label from company	Conc. (%)	Number	Label from company	Conc. (%)
1	Sandalore	4.0	1	Citronellol	1.0
2	Rose oxide	2.0	2	Isobutyl quinoline 54	1.0
3	Stemone	3.0	3	Linalyl acetate	1.0
4	Styrallyl acetate	2.0	4	Nonanal	1.0
5	Carrot	2.0	5	Turpentine	3.0
6	Butanol	0.5	6	Ethyl acetoacetate	1.0
7	Dihydromyrcenol	1.0	7	Basilic (Comoros, EO)	2.0
8	cis-3-Hexenyl salicylate	3.0	8	Allyl amyl glycolate	1.0
9	Methyl octine carbonate	1.0	9	Rosemarel	3.0

Conc., concentration in volume (%); EO, essential oil.

To study the retrieval of past events, two approaches are typically used: *ecological* and *laboratory-based* approaches. In the *ecological* approach, experimenters test autobiographical memory by interrogating participants about real-life memories encoded in their past (e.g., Fink et al., 1996; Janata, 2009; Levine et al., 2004; Nadel et al., 2007; Piolino et al., 2004). The participants must relate memories evoked by a cue (e.g., photographs, faces, sentences, or music), an approach that is quite ecological, as it is close to the conditions under which real-life recall typically occurs. However, experimenters cannot control the veracity of the recalled events. In the *laboratory-based* approach, experimenters test the memorization of artificial episodes created in the laboratory using recognition tasks (e.g., Daselaar et al., 2003; Donaldson et al., 2010; Konishi et al., 2000; Watanabe et al., 2008). The participants study a list of items (e.g., pictures, words, sounds, or odors) and, at a later point, must distinguish between these 'old' items (targets) and 'new' items (distractors). This method controls for the encoding conditions, the retention time and the veracity of the retrieval. However, the to-be-remembered information is often one-dimensional (*What*) and is therefore poor in comparison with a real-life episode. McDermott et al. (2009) have underscored the interest to propose a new approach to the study and understanding of human episodic memory, one that should be halfway between these two methods and should retain the respective advantages of each. Toward this end, we developed a laboratory-based method to investigate episodic memory that is as ecologically valid as possible but in which encoding, retention delay and retrieval are fully controlled.

In our approach, the to-be-remembered episodes are unique, rich, close-to-real-life episodes, and in agreement with the definitions of episodic memory proposed by Tulving (1972), and Easton and Eacott (2008). The episodes were composed of three dimensions: odors (*What*) positioned at specific locations on a board (*Where*) and presented in a visual context (i.e., a picture of a landscape, *Which context*). During the encoding phase, the participants freely explored the episodes. After consolidation, episodic memories were explored using simple recognition and retrieval tasks, ensuring the evaluation of the memory content accuracy. This protocol did not address the conscious re-experience of past events, and therefore investigate what Clayton and colleagues referred to as episodic-like memory (Clayton et al., 2001; Easton and Eacott, 2008).

We used odors as cues for two reasons. First, among all types of stimuli, odors are known to be especially evocative reminders, the best illustration of this phenomenon being the Proust's Madeleine story (Proust, 1913). Experimental studies have later shown that odor-evoked memories are more emotional, more associated with subjective experience, and more vivid than those recalled by other sensory cues (Goddard et al., 2005; Herz, 2004; Herz and Cupchik, 1995; Herz et al., 2004; Larsson and Willander, 2009; Miles and Berntsen, 2011). This strong connection between olfaction, emotion and memory makes olfaction a privileged sense for accessing memories. Additionally, because odors are highly difficult to identify (Jonsson and Olsson, 2003; Lawless and Engen, 1977), participants favor perceptual cues to encode them and thereby limit the use of verbal processes. The use of odors thus allows us to specifically explore episodic, but not semantic, memory.

The aims of the current study were twofold. First, we wanted to validate our novel paradigm designed for the study of episodic memory, and second, we wanted to test the adaptability of this procedure to the constraints of functional magnetic resonance imaging (fMRI). Experiment 1 evaluated the recognition of non-familiar odors and the retrieval of spatio-contextual environments associated with these odors. Experiment 2 addressed the effects of trial repetition on memory scores, which was necessary to adapt the recall procedure to fMRI constraints.

2. Experiment 1

2.1. Objective and design

Experiment 1 was principally designed to validate our methodological approach for the study of episodic memory. This behavioral validation consisted of an evaluation of participants' abilities to freely encode unique rich episodes and to later recall these episodes during odor recognition and episodic retrieval tasks.

2.2. Materials and methods

2.2.1. Participants

Twenty-two healthy participants [14 women; age: 22.6 ± 7.9 (mean $\pm$ standard deviation)] consented to participate in the experiment. These participants were recruited by means of posters or electronic mail on campus and received 20 euros in compensation. The participants reported normal senses of smell and no visual impairments. The study was conducted in accordance with the Declaration of Helsinki. All of the participants provided written informed consent as required by the local Institutional Review Board, according to French regulations for biomedical experiments with healthy volunteers [Ethical Committee of CPP Sud-Est IV (CPP 11/007), ID RCB: 2010-A-01529-30, January 25, 2011].

2.2.2. Odorous stimuli

Eighteen odorants were selected a priori based on their distinctiveness, neutral valence, and relatively low familiarity. The odorants were selected to be distinguishable but hardly identifiable. They were divided into two sets of 9 odorants each: Set 1 of target odorants and Set 2 of distractor odorants (Table 1). The odorants consisted of essential oils and single – or mixtures of – monomolecular chemicals. Their concentrations were adjusted by two experimenters (authors of the paper: ALS and JP) during successive trials to equalize the subjective intensity of all of