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MEMORY IN TIME: ELECTROPHYSIOLOGICAL COMPARISON BETWEEN REALITY FILTERING AND TEMPORAL ORDER JUDGMENT

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Abstract—Orbitofrontal reality filtering (ORF) denotes a little known but vital memory control mechanism, expressed at 200–300 ms after stimulus presentation, that allows one to sense whether evoked memories (thoughts) refer to present reality and can be acted upon, or not. Its failure induces reality confusion evident in confabulations that patients act upon and disorientation. In what way ORF differs from temporal order judgment (TOJ), that is, the conscious knowledge about when something happened in the past, has never been explored. Here we used evoked potential analysis to compare ORF and TOJ within a combined experimental task and within a comparable time frame, close to the experienced present. Seventeen healthy human subjects performed an experiment using continuous recognition tasks that combined the challenges of ORF and TOJ. We found that the two mechanisms dissociated behaviorally: subjects were markedly slower and less accurate in TOJ than ORF. Both mechanisms evoked similar potentials at 240–280 ms, when ORF normally occurs. However, they rapidly dissociated in terms of amplitude differences and electrical source from 310 to 360 ms and again from 530 to 560 ms. We conclude that the task of consciously ordering memories in the immediate past (TOJ) is effortful and slow in contrast to sensing memories' relation with the present (ORF). Both functions invoke similar early electrocortical processes which then rapidly dissociate and engage different brain areas. The results are consistent with the different consequences of the two mechanisms' dysfunction: while failure of ORF has a known clinical manifestation (reality confusion as evident in confabulation and disorientation), the failure of TOJ, as tested here, has no such known clinical correlate.

Key words: reality filtering, orbitofrontal cortex, source memory, temporal order judgment, evoked potentials, time.

INTRODUCTION

The experience of remembering is fundamental to human action and thinking. A crucial aspect of memory is time. Two capacities are clearly important: the ability to sense whether a memory (thought) pertains to present reality – and may be acted upon – and the ability to recollect the temporal context in which a memory was acquired.

An impairment of the former capacity is associated with reality confusion, as evident in disorientation and confabulations that patients act upon (Schnider, 2008, 2013). For example, a 58-year-old woman left the examination convinced that she had to feed her baby – who was 35 years old at the time (Schnider, 1996); a dentist hospitalized after rupture of an aneurysm of the anterior communicating artery repeatedly left the hospital in the conviction that patients were waiting for him at his clinic (Ptak and Schnider, 1998). Schnider and colleagues explained this kind of behavior by the failure of a specific mechanism they now call orbitofrontal reality filtering (ORF) (Schnider, 2008, 2013). They found that, when reality confusing patients made repeated runs of a continuous recognition task, all of them composed by the same picture set, they produced increasingly more false positive responses, in contrast to correctly oriented amnesics (Schnider et al., 1996a; Schnider and Ptak, 1999; Nahum et al., 2012). Healthy subjects performing such a task had activation of the posterior orbitofrontal cortex and subcortical structures (Schnider et al., 2000; Treyer et al., 2003), which corresponds to the main lesion site of reality confusing patients (Schnider et al., 1996a; Schnider and Ptak, 1999; Schnider, 2013). Successful completion of the task by healthy subjects was associated with a frontal positivity in evoked potential responses at 200–300 ms, indicating that reality filtering (RF) occurs before the content of an upcoming thought or memory is processed at 400–600 ms (Schnider et al., 2002; Wahlen et al., 2011; Schnider, 2013).

ORF bears superficial resemblance to well-known memory-monitoring models. Strategic retrieval describes

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Abbreviations: ANOVA, analysis of variance; DRF, distracters within the reality filtering task; DTJ, distracters within the temporal judgment task; EEG, Electroencephalography; ERPs, event-related potentials; LAURA, local auto-regressive average; ORF, orbitofrontal reality filtering; RF, reality filtering; ROI, region of interest; TANOVA, topographic analysis of variance; TJ, temporal judgment; TOJ, temporal order judgment; TRF, targets within the reality filtering task; TTJ, targets within the temporal judgment task.

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a hypothetical series of processes leading up the evocation and verification of memories. It has been claimed to encompass ORF and to explain confabulation (Moscovitch and Melo, 1997; Gilboa et al., 2006). Experimental testing, however, showed that monitoring, as described within this model, electrophysiologically dissociated from ORF (Wahlen et al., 2011). In amnesic patients, only deficient ORF, but not strategic monitoring, was associated with reality confusion, as evident in disorientation and inappropriate acts in agreement with confabulations (Bouzerda-Wahlen et al., 2013). Failures of source monitoring, the ability to judge the precise source (context, temporal frame, etc.) of a memory, is also a generally accepted explanation for confabulation (Johnson et al., 1993). Experimental evidence has not supported this claim (Johnson et al., 1997), and an evoked potential study demonstrated a dissociation between context source monitoring and ORF (Bouzerda-Wahlen et al., 2014). Clearly, the ability to sense a memory's (thought's) relation with the present, as reflected in ORF, is different from the ability to decide whether and how a memory refers to the past, as covered by traditional memory-monitoring models.

Behavioral correlates of a disturbed sense for the temporal context in which memories were acquired are less clear. The capacity is usually measured with recency or temporal order judgment (TOJ) paradigms in which two lists of items are presented and subjects are asked to recall whether a given item had appeared in the first or in the second list or which one had been presented more recently (e.g. Tendolkar and Rugg, 1998; Duarte et al., 2010). The ability to correctly place memories in their temporal sequence has been suggested to be a mechanism for confabulation (Van der Horst, 1932; Talland, 1961; Dalla Barba et al., 1997), previously also for disorientation (Kraepelin, 1909), which has been the topic of very few studies. Data were ambiguous: difficulties in TOJ did not appear specific to confabulation and disorientation (Schnider et al., 1996b; Johnson et al., 1997). Disordered temporal order memory has been observed after dorsolateral prefrontal (Milner et al., 1985, 1991; Shimamura et al., 1990), medial temporal lobe, and diencephalic lesions (Kopelman et al., 1997). Imaging studies in healthy individuals demonstrated activation of the dorsolateral prefrontal cortex (Zorrilla et al., 1996; Konishi et al., 2002), together with cuneus, precuneus and right posterior parietal regions (Cabeza et al., 1997). In evoked potential studies, recency judgment evoked bilateral frontal positivity from around 300 ms (Tendolkar et al., 2004).

These observations indicate a functional and electrophysiological dissociation between ORF and TOJ. However, the paradigms used to explore them not only differed in design but also in temporal frame: while healthy subjects need to perform continuous recognition tasks in rapid succession to challenge ORF (and induce orbitofrontal cortex activation) (Schnider, 2008, 2013), TOJ has traditionally been tested on items separated by minutes (e.g., Tendolkar et al., 2004; Grove and Wilding, 2008).

For the present study, we designed an experimental task exploring the two processes within a similar time frame around the extended present (Fraisse, 1984), with task components separated by short intervals (around 1 min). Given the suspected dissociation between the two mechanisms, we expected that ORF – an intuitive faculty – would behaviorally dissociate from explicit, typically effortful TOJ by more accurate and faster performance. On the electrophysiological level, we expected stimuli critical for ORF to induce a frontal positivity at 200–300 ms. In contrast, we expected the stimuli specific for TOJ to induce potential changes at a later stage of processing, beyond 300 ms.

EXPERIMENTAL PROCEDURES

Participants

Twenty-three right-handed healthy subjects gave written informed consent and were paid to participate in the study, which was approved by the Institutional Ethical Committee. They reported no history of neurological or psychiatric disorders or medication use. Five subjects were excluded from the study because of poor signal quality and one subject because of poor comprehension of the task. Seventeen subjects (11 women and six men, age 24 ± 3.3 years) were included in the analysis.

Procedure and task

We devised a task composed of four different blocks. Two blocks tested RF, two tested TOJ. The composition of the task is shown in Fig. 1. Blocks' order was pseudo-randomized: half of the subjects started with the RF condition, the other half with the temporal judgment (TJ) condition. Blocks were separated by 5 min to avoid fatigue.

Each block was composed of a different set of images and was divided in 3 runs: the first two runs (Fig. 1A) corresponded to the learning phase, in which two different sets of 40 concrete line drawings (Snodgrass and Vanderwart, 1980) were shown for the first time (distracters, D; $n = 40$) and then repeated after 6–8 intervening stimuli (repetitions, targets, T; $n = 40$). Subjects had to answer the following question: ''Have you already seen this image within this run?'' by pressing the left button with the right index to indicate ''yes'' or the right button with the right middle finger to indicate ''no''. These two runs were separated by a 3-min pause.

In the third run of each block, we tested alternatively RF or TOJ.

RF (Fig. 1B) was tested according to the same logic as in previous studies (Schnider et al., 2002; Schnider, 2008, 2013): all images from the two previous runs were mixed together to compose a continuous recognition run with picture repetitions after 6–8 intervening images. Subjects had to answer the following question: ''Have you already seen this image within this run?'' by pressing the left button with the right index to indicate ''yes'' or the right button with the right middle finger to indicate ''no''. In the following, picture recurrences within this run will be designated ''targets within reality filtering task (TRF)''. Items appearing for the first time within the third run (previously presented either in the first or the second