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Episodic context binding in task switching: Evidence from amnesia

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The purpose of the present study was to investigate whether amnesic patients show a bivalency effect. The bivalency effect refers to the performance slowing that occurs when switching tasks and bivalent stimuli appear occasionally among univalent stimuli. According to the episodic context binding account, bivalent stimuli create a conflict-loaded context that is re-activated on subsequent trials and thus it is assumed that it depends on memory binding processes. Given the profound memory deficit in amnesia, we hypothesized that the bivalency effect would be largely reduced in amnesic patients. We tested sixteen severely amnesic patients and a control group with a paradigm requiring predictable alternations between three simple cognitive tasks, with bivalent stimuli occasionally occurring on one of these tasks. The results showed the typical bivalency effect for the control group, that is, a generalized slowing for each task. In contrast, for amnesic patients, only a short-lived slowing was present on the task that followed immediately after a bivalent stimulus, indicating that the binding between tasks and context was impaired in amnesic patients.

1. Introduction

Cognitive control is the ability to maintain current goal representations in face of conflict. It enables selection of goal-relevant features while suppressing distracting ones (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004). However, how cognitive control is exerted to adjust and fine-tune performance in face of conflict and more generally, whether cognitive control effects reflect the operation of a cognitive control system or instead should rather be conceptualized as memory binding processes (Altman & Gray, 2008; Egner, 2007; Hommel, 2004; Mayr, Awh, & Laurey, 2003; Verguts & Notebaert, 2009), or both, remains an open question. Here we investigate one particular effect of cognitive control—the bivalency effect. We specifically test whether intact memory processes are required by comparing performance of amnesic patients to a healthy control group.

The bivalency effect refers to the phenomenon that, when people switch between a series of tasks and occasionally one of these tasks involves bivalent stimuli, that is, stimuli with relevant features to two tasks, subsequent performance is slowed. Critically, the slowing occurs even on trials that have no overlapping features with the bivalent stimuli. For example, in an initial study by Woodward, Meier, Tipper, and Graf (2003), participants switched between a parity decision (odd vs. even numerals), a colour decision (red vs. blue symbols), and a case decision (uppercase vs. lowercase letters), repeatedly and in a fixed order. On most of the trials the stimuli were univalent (i.e., black numerals for the parity decision, coloured shapes for the colour decision, and black letters for the case decision). However, occasionally, on some case decisions the letters were presented in colour, thus turning them into bivalent stimuli. The results showed that performance was not only slowed for these bivalent stimuli, but also for all the subsequent univalent trials, even those with stimuli that shared no relevant features with the bivalent stimuli (i.e., the parity decisions). Woodward et al. noted that this result challenges task-switching theories that focus primarily on bottom-up processes, that is, processes initiated and guided by the stimuli and their particular features (e.g., Allport & Wylie, 2000; Meiran, 2008; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995). These theories can account for the slowing in response to univalent stimuli, which share a relevant feature with the bivalent stimuli (i.e., those used for case and colour decisions). However, they cannot account for the slowing in response to univalent stimuli, which share no features with the bivalent stimuli (i.e., those used for the parity decisions).

Follow-up studies have established that the bivalency effect is robust across a variety of different tasks, across different modalities

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and bivalent stimuli, and that it leads to an enduring slowing, affecting performance on univalent stimuli up to twenty seconds after the occurrence of a bivalent stimulus (Meier, Woodward, Rey-Mermet, & Graf, 2009). Moreover, it is independent from response set priming and it occurs for repetition trials that have overlapping stimulus features (Rey-Mermet & Meier, 2012a, 2012b). Theoretically, it is possible that when encountering bivalent stimuli, the cognitive system adjusts control, which results in a more cautious response style. The underlying processes may be related to binding processes that are consecutively associating stimuli, tasks and the context in which they occur. When a bivalent stimulus occurs, stimuli and tasks are associated with a context-loaded context. On subsequent trials, the reactivation of this episodic context representation interferes with performance on univalent trials. This account can explain why performance is slowed even on those univalent trials with non-overlapping stimulus features. Critically, memory processes are required for the expression of the bivalency effect (Meier et al., 2009; Meier & Rey-Mermet, 2012; Rey-Mermet & Meier, 2012a).

The available evidence from functional magnetic resonance imaging (fMRI) supports the notion that the bivalency effect reflects an adjustment of cognitive control. Woodward, Metzak, Meier, and Holroyd (2008) contrasted univalent stimuli from a condition with purely univalent stimuli and univalent stimuli from a condition in which bivalent stimuli were occasionally intermixed on one of the tasks. The results showed that the bivalency effect was associated with activation in the dorsal anterior cingulate cortex (dACC), a brain area recruited for the adjustment of cognitive control (see Botvinick et al., 2001). Similarly, using event-related potentials, Grundy et al. (2011), found amplitude differences at frontal electrodes within time windows of 275–450 ms and 500–550 ms. They interpreted these modulations as "suppression of processing carried over from irrelevant cues". Moreover, consistent with the fMRI results, source dipole analyses revealed dipole locations at or close to the dACC. Thus, the bivalency effect is associated with activations in brain areas that signal adjustment of cognitive control triggered by conflict processing. Here, we investigate what exactly triggers conflict in the absence of bivalent stimuli, that is, when processing purely univalent stimuli. We have suggested previously that the re-activation of a representation of conflict that has been build up by processing the conflict-loaded task-triplet is a likely explanation. According to this "episodic context binding" hypothesis, each sequential presentation of a task-triplet (e.g., parity–color–case) represents a separate context. When a bivalent stimulus is presented on one of these tasks, the conflict that is triggered spreads to the representation of the whole context. For the next task-triplet, this representation is reactivated and performance is slowed for all the stimuli, even for those that have no overlapping features with the bivalent stimulus (Meier & Rey-Mermet, 2012).

According to this explanation, we would expect that binding processes take place on each trial (i.e., stimuli, tasks, and task-triplets acquire a history, cf. Meier et al., 2009; Waszak, Hommel, & Allport, 2003) and thus, we would also predict memory-related brain activations. However, when contrasting univalent blocks with and without bivalent stimuli in an fMRI or ERP-study these activations cancel each other out, explaining the absence of memory-related brain activations in these studies. Here we specifically investigated the involvement of memory processes in the bivalency effect by testing a sample of amnesic patients who have a profound memory deficit.

We tested a group of 16 severely amnesic patients and a healthy control group. During three blocks, all participants performed a parity decision on numerals (odd vs. even), a colour decision on symbols (red vs. blue), and a case decision on letters (upper vs. lowercase). In the first and third blocks (the purely univalent blocks), all stimuli were univalent. In the second block (the mixed block), some letters for the case decisions were presented in colour (red or blue), which turned them into bivalent stimuli. Our motivation for involving amnesic patients was to test whether their profound deficit in memory binding, in particular binding an event to a particular context (e.g., Chun & Phelps, 1999; Hannula, Tranel, & Cohen, 2006; Pascalis, Hunkin, Bachevalier, & Mayes, 2009), would affect the bivalency effect. Several studies have demonstrated that the binding deficit in amnesia is not restricted to long-term memory, but also affects short-term bindings such as those thought to be involved in the bivalency effect (Ezzyat and Olson (2006); Olson, Moore, Stark, & Chaterjee, 2006; Olson, Moses, Riggs, & Ryan, 2012 for a recent review). Thus, we hypothesized that if episodic context binding is involved in the bivalency effect, amnesic patients will show a considerable reduction in the magnitude of the bivalency effect. In contrast, if episodic context binding is not necessary for the formation of the bivalency effect, then amnesic patients will show a normal bivalency effect.

Table 1
Demographic characteristic.

Patient ID	Age (years)	Education (years)	Sex	Aetiology	Time since onset (months)
1	46	13	F	Herpes encephalitis	136
2	59	18	M	Haemorrhage	70
3	42	12	F	Hypoxia	63
4	57	19	M	Herpes encephalitis	82
5	40	16	F	Haemorrhage	91
6	53	13	M	Haemorrhage	150
7	43	13	M	Hypoxia	216
8	68	15	M	Infarction	218
9	58	19	M	Haemorrhage	152
10	68	11	M	Lupus erythematosus	213
11	51	17	M	Haemorrhage	167
12	58	13	M	Infarction	8
13	52	11	M	Haemorrhage	11
14	58	12	M	Hypoxia	5
15	22	11	M	Infarction	5
16	39	17	M	Hypoxia	birth
Mean	50.9 ± 11.8	14.4 ± 2.9	13 M 3 F		
Control group Mean	51.3 ± 11.7	15.0 ± 2.3	12 M 4 F		

Note. *F*=female; *M*=male.