Neuropsychologia 47 (2009) 1362–1373

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

The role of dual-task and task-switch in prospective memory: Behavioural data and neural correlates

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ARTICLE INFO

Article history:
Received 24 February 2008
Received in revised form 15 January 2009
Accepted 25 January 2009
Available online 2 February 2009

Keywords:
Prospective memory
Dual-task
Task-switch
Cognitive control
ERPs

ABSTRACT

Event-based prospective memory (PM) requires remembering the delayed execution of an intended action in response to a pre-specified PM cue while being actively engaged in an ongoing task in which the cue is embedded. To date, experimental paradigms vary as to whether or not they require participants immediately to stop working on the ongoing task whenever they encounter a PM event (cue) and directly switch to the prospective action (task-switch approach). Alternatively, several other paradigms used in the literature encourage participants to continue working on the ongoing task item after the cue, and only then, perform the prospective action (dual-task approach). The present study explores the possible behavioural and electrophysiological effects that both approaches may have on PM performance. Seventeen young adults performed both versions of a standard PM task in a counterbalanced order during which behavioural data and electroencephalogram (EEG) were recorded. Behavioural data showed a decrement in PM performance in the task-switch compared to the dual-task condition. In addition, EEG data revealed differences between the dual-task and task-switch approach in event-related potential (ERP) components associated with response inhibition and with post-retrieval monitoring (i.e. late positive complex). No differences between the two tasks were found with regard to the PM event detection processes (i.e. N300) and the retrieval of the intended action from long-term memory. In sum, findings demonstrate that it does make a difference which task approach is applied and suggest that dual-task and task-switch paradigms may result in different processing and neurophysiological dynamics particularly concerning attentional resources and cognitive control.

1. Introduction

Prospective memory (PM) refers to the processes associated with remembering to perform an intended action at some time in the future (Ellis, 1996). Remembering to give a message to a colleague or to take medication according to schedule can be considered examples of everyday prospective remembering. Conceptually, two types of PM paradigms have been distinguished (Einstein & McDaniel, 1996): *event-based* paradigms, in which the event (cue) for the appropriate execution of the PM task is a specific externally presented event (e.g. the appearance of a specific colleague or a target word on the computer screen); and *time-based* paradigms, in which the intended action has to be executed at a specific point in time (e.g. at noon or every 10 min). The present investigation focused on event-based PM.

A key procedural feature of all PM paradigms is that they require the self-initiated execution of the intended action while being engaged in an ongoing activity (Ellis & Kvavilashvili, 2000), for example remembering to call a colleague while being busy marking student papers. Empirically, this requirement is paralleled in the laboratory by involving participants in an attentionally demanding task (e.g. continuously rating words for concreteness and pleasantness) in which the prospective memory events are embedded as apparently normal ongoing task items (e.g. remembering to press a specific response key whenever a specific target word appears among the words to be rated; e.g. Einstein, Smith, McDaniel, & Shaw, 1997).

While, by now, this requirement is acknowledged as a standard feature of PM paradigms across all areas of PM research (e.g. Ellis & Kvavilashvili, 2000; Ellis & Freeman, 2008; Kliegel, Jäger, Altgassen, & Shum, 2008), surprisingly, one major aspect of the general empirical procedure varies across paradigms applied: whether or not the participant has to refrain from dealing with the ongoing activity coincidently with the PM event and immediately switch to the prospective action. In other words, some PM paradigms are

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0028-3932/$ – see front matter
doi:10.1016/j.neuropsychologia.2009.01.034

instructed as *dual-task* procedures: here, the participant has to work on both tasks simultaneously. They must remember and execute the prospective action while also responding to the ongoing task item when a PM event occurs; e.g. by first rating the PM event word for its concreteness and then hitting the prospective target key (e.g. Hicks, Marsh, & Cook, 2005). In contrast, other PM paradigms are instructed as *task-switch* procedures: here, the participant has immediately to stop working on the ongoing task as soon as they encounter a PM event and directly perform the prospective action; e.g. by refraining from rating the target word for its concreteness and immediately hitting the prospective target key (e.g. Burgess, Scott, & Frith, 2003). Interestingly, in reviewing the literature, many studies either do not clearly specify the route they took in the methods descriptions (e.g. McDaniel, Guynn, Einstein, & Breneiser, 2004) or explicitly leave it to the participant to decide how to perform the task (e.g. Smith, 2003; Smith, Hunt, McVay, & McConnell, 2007).

At least one line of reasoning, however, suggests that it may not be an arbitrary choice whether to introduce the PM paradigm as a dual-task or task-switch procedure. While both dual-task and task-switch are known to require the recruitment of cognitive resources (e.g. Baddeley, Chincotta, & Adlam, 2001), a handful of studies on the development of PM have indicated that PM paradigms that require the active interruption of the ongoing activity appear to be particularly difficult for relatively young or relatively old participants. This is presumably because of the need to suppress (inhibit or interrupt) the tendency to respond in accordance with ongoing activity requirements. For example, Kvavilashvili, Messer, and Ebdon (2001) found that in a sample aged 4–7 age effects were mostly related to the necessity of interrupting the ongoing task in order to perform the PM action. Similarly, Wang, Kliegel, Liu, and Yang (2008) demonstrated age differences in event-based PM across 3–5 years, in particular with a PM task that required active ongoing task interruption. In contrast, a task version that did not require active ongoing task interruption (here, the PM event was placed at the end of the ongoing task) did reveal age-invariant performance. That this also holds across the entire lifespan was recently demonstrated by Kliegel, Mackinlay, and Jäger (2008b) who experimentally manipulated, in young and older school-aged children as well as young and older adults, the degree to which the task encourages active interruption in a complex multitask PM paradigm. Importantly for the present purpose, age differences in delayed intention execution were substantially greater when active task interruption was necessary. Converging evidence is also provided by Cockburn's (1995) clinical data reporting a frontal lobe patient who performed poorly in tests of executive function and who had a particular (though not selective) deficit in inhibitory control. Importantly, the patient was selectively unable to interrupt ongoing activities to perform an intended action despite adequate encoding, monitoring and recall of the content of the intention.

In summary, there is evidence to suggest that PM paradigms, which explicitly require active ongoing task interruption, require supplementary cognitive control and inhibitory processes in order to switch to PM execution. However, to date, both paradigms have been largely used interchangeably in the literature and a direct comparison of the two task versions has not been reported. In terms of PM responses, the task-switch version could be seen as a more difficult dual-task procedure involving two production rules (i.e. 1. stopping and 2. pressing the space bar), with the difference that the two tasks here are in opposition to one another. In contrast, in the traditional dual-task version the production rule is the same (i.e. 'do').

Further evidence underlining the need to distinguish both PM task procedures can be derived from considering cognitive processes involved in dual-task and task-switch procedures in general. In dual-task paradigms, two tasks have to be carried out concurrently (see Pashler, 1984, 1994) and it has repeatedly been shown that this reduces the amount of resources available in comparison to single task performance. In consequence, performance in the primary and/or secondary tasks is reduced when compared to single task performance. Theories of dual-task performance have suggested that the interference between two tasks results from a processing mechanism that is limited in capacity and allows processing of only one task at a time (Pashler, 1994; Ruthruff, Pashler, & Hazeltine, 2003). However, the need to process two tasks simultaneously also allows parallel loading of the two response programs. On one hand, this slows down the time needed to execute the primary task (compared to executing it alone). On the other hand, it may also reduce the time needed to process the secondary task (i.e. graded capacity-sharing model, Pashler, 1994; Ruthruff et al., 2003).

In contrast, the most prominent phenomenon observed in task-switch experiments is that participants generally need additional time when the mapping between stimulus and response is changed during an experiment (task-switch trials). This delay in response time is referred to as 'switch cost' and has been extensively replicated across a number of different task-switch procedures and across several age groups (Rogers & Monsell, 1995).

In recent years the neural basis of dual-task and task-switch paradigms has been studied extensively (Crone, Wendelken, Donohue, & Bunge, 2006; Cutini et al., 2008; D'Esposito et al., 1995; Dove, Pollman, Schubert, Wiggins, & von Cramon, 2000; Herath, Klingberg, Young, Amunts, & Roland, 2001; Kimberg, Aguirre, & D'Esposito, 2000; Schubert & Szameitat, 2003; Szameitat, Lepsien, von Cramon, Sterr, & Schubert, 2006). The picture emerging from the comparison between the neural correlates of dual-task versus task-switch paradigms reveals that both tasks recruit largely overlapping fronto-parietal neural circuits. To our knowledge, Dreher and Grafman's (2003) study is the only one that has attempted directly to investigate the differences in neural activation between dual-task and task-switch. They pointed out that the rostral anterior cingulate cortex serves to resolve conflicts between stimulus–response associations when performing two tasks simultaneously, while the lateral prefrontal cortex dynamically selects the neural pathways needed to perform a given task during a task-switch.

With regard to the neural substrate of PM, recent neuroimaging studies have shown that the rostral prefrontal cortex (Brodmann area 10) may play an important role in the maintenance and realisation of delayed intentions (Burgess et al., 2003; den Ouden, Frith, Frith, & Blakemore, 2005; Martin et al., 2007; McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999; Okuda et al., 2007; Simons, Schölvinck, Gilbert, Frith, & Burgess, 2006).

From a neurophysiological perspective, the few electrophysiological data available reveal a specific sensitivity of the P3 component for processing resources involved in dual-task paradigms (Kok, 1997). On the other hand, task-switch event-related potential (ERP) studies (e.g. Barceló, Muñoz-Céspedes, Pozo, & Rubia, 2000; Barceló, 2003; Gehring, Bryck, Jonides, Albin, & Badre, 2003; Poulsen, Luu, Davey, & Tucker, 2005; Rushworth, Passingham, & Nobre, 2005; Swainson et al., 2003; Swainson, Jackson, & Jackson, 2006) have shown an increased positivity in anticipation of cued switch trials relative to repeat trials, particularly over parietal electrodes. Recently, in task-switch paradigms the response inhibition was associated with a centro-frontal negativity that was observed only after preceding go trials but not after preceding no-go trials (Astle, Jackson, & Swainson, 2006). The negativity effect, therefore, appears to be specific to the situation where a response must be suppressed, possibly reflecting active 'top-down' inhibition of an immediate and/or pressing response tendency (Astle et al., 2006; Swainson et al., 2003).

With regard to the neurophysiological correlates of PM, the first component previously identified as being associated with PM tasks is the N300, which is described as a negativity reaching maximum