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Biological Psychology 72 (2006) 278–290

BIOLOGICAL PSYCHOLOGY

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Behavioural and electrophysiological measures of task switching during single and mixed-task conditions

Philippe Goffaux [a,b], Natalie A. Phillips [a,b,c,*], Marco Sinai [a,b], Dolores Pushkar [a,b]

[a] Centre for Research in Human Development, Department of Psychology, Concordia University,
7141 Sherbrooke Street West, Montreal, Que., Canada H4B 1R6
[b] Centre for Research in Human Development, Concordia University, Montreal, Que., Canada
[c] Lady Davis Institute for Medical Research/Jewish General Hospital, Montreal, Que., Canada

Received 14 July 2005; accepted 23 November 2005
Available online 18 January 2006

Abstract

In order to understand how the brain prepares for and executes a switch in task demand, we measured reaction time (RT), accuracy, and event-related brain potentials associated with performance in single and mixed-task blocks using a cued design. Our results show that trials which repeat in a mixed-task block (repeat trials) were more demanding than trials which repeated in a single-task block, as reflected by the presence of a RT mixing cost and by the presence of a smaller target-locked positivity (P3b) on repeat trials. Within a mixed-task block, repeat and switch trials also differed, where repeat trials showed evidence of greater preparation (larger cue-locked negativity), more efficient target processing (larger target-locked P3b), and shorter RTs. In addition, the cue-locked negativity difference remained despite equating repeat and switch trials on RT, suggesting that this negativity difference is specific to the switching process. Our results are discussed in light of existing models of task switching.

Keywords: Task switching; Switch costs; Working memory; Preparation; Event-related brain potentials; P300; Negative slow wave

Multitasking has recently become a hot topic for empirical research, perhaps partly because we are increasingly required to work in such a way. As our workdays increasingly require that we execute multiple tasks (for example, when we must answer the phone while writing an e-mail), our attention must be diverted from one task to another and it is logical that our performance comes to suffer. In fact, recent research shows that switching frequently between different tasks takes a toll on efficiency as measured by reaction time (RT) tasks (e.g., see Rogers and Monsell, 1995; Meiran et al., 2000; Rubinstein et al., 2001). The decrement in efficiency observed when one is multitasking is believed to come, in large part, from the need to shift attention and implement changes in cognitive routines, both of which require conscious, effortful control.

The goal of this study was to explore behavioural and electrophysiological measures of multitasking using a task switching paradigm. In the following paragraphs, we provide a brief overview of task switching and of the different associated costs. Following this, we review some of the most pertinent neurophysiological studies of task switching that have been published.

In one of the first of the recent generation of studies, Rogers and Monsell (1995) argued that effective switching requires the reconfiguration of task set. This, in turn, entails shifting attention and retrieving and implementing relevant stimulus–response action rules (Rubinstein et al., 2001). Rogers and Monsell (1995) had participants alternate tasks predictably on every second trial in a given block of trials, such that a participant had to either repeat the same task or switch to a different task. This design, known as the alternate runs paradigm, allowed Rogers and Monsell (1995) to isolate transient cognitive control processes and show that it takes longer to switch between competing task-demands than it does to repeat the same task, a phenomenon labelled the local switch cost. They also showed that the local switch cost decreases when the time prior to a predictable switch trial increases, indicating that one can engage in advanced preparation to facilitate the reconfiguration of the task set. However, no matter how much preparatory time was given, it remained more costly to switch between tasks than it did to repeat a task, which suggests that advanced preparation alone is not sufficient to complete task set reconfiguration. The local switch cost that

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* Corresponding author. Tel.: +1 514 848 2218; fax: +1 514 848 4537.
E-mail address: Natalie.Phillips@concordia.ca (N.A. Phillips).

0301-0511/$ – see front matter
doi:10.1016/j.biopsycho.2005.11.009

remains despite a long preparatory interval is known as a residual switch cost. Rogers and Monsell concluded that although the active or endogenous control processes engaged during a long preparatory interval allow a participant to complete part of the task set reconfiguration process in advance, the presentation of the target stimulus is necessary to complete this process. This latter phenomenon reflects externally driven, target-triggered processes. In short, Rogers and Monsell proposed a two-step model where both preparatory, pre-target, endogenously controlled processes and target-driven, exogenous processes contribute to the reconfiguration of task sets under goal-directed conditions.

Rogers and Monsell's alternate runs paradigm stood in contrast to the way multitasking had been investigated up to that point. Previous work on task switching (Jersild, 1927; Spector and Biederman, 1976) had compared RT performance between blocks of trials which continually repeated (i.e., homogeneous or single-task blocks) and blocks which contained only switch trials (i.e., heterogeneous or mixed-task blocks). This comparison revealed larger RTs for heterogeneous task blocks than for homogeneous task blocks, but could not be exclusively tied to the cognitive control processes underlying the switch cost. Important state differences including fatigue, motivation, and arousal could conceivably explain RT differences between homogeneous and heterogeneous blocks. In order to control for this, Rogers and Monsell, as well as others (Allport et al., 1994; Meiran, 1996; Meiran et al., 2000), compared repeat and switch trials when these occurred within the same block of mixed trials, thus minimising block-related differences. However, a comparison between performance on homogeneous and heterogeneous blocks remains interesting. Indeed, unlike homogeneous blocks, heterogeneous blocks require that multiple, competing task sets be maintained and co-ordinated in working memory (Kray and Lindenberger, 2000). Competing task sets are believed to interfere with performance, even on heterogeneous repeat trials that require no switch in task set (Los, 1999). The cognitive control processes exerted to deal with this interference is captured by comparing homogeneous RTs to heterogeneous repeat RTs and is defined as the mixing cost (Meiran et al., 2000, 2001). Notwithstanding potential block differences in arousal and motivation, the homogeneous versus heterogeneous repeat RT difference is believed to capture an important task switching difference in sustained cognitive control processes and continues to be a useful index of task switching.

Although RT and accuracy are sensitive measures of changes in task set, they do not provide information on how the brain prepares for and responds to these changes. To adequately observe the cortical activity related to switching between tasks and repeating tasks, the neuroimaging technique of choice should be sensitive to processing changes evoked over very short periods of time. Given their high temporal resolution, electroencephalographic recordings are ideally suited to capture these changes. When time-locked to the presentation of a stimulus event and averaged across trials, electroencephalographic recordings reflect voltage variation in cortical activity associated with specific events. Known as event-related brain potentials (ERPs), these time-locked voltage changes are defined according to their polarity (positive or negative), latency (ms), amplitude (μV), and topographic scalp distribution. To date, only a handful of studies have used ERPs to examine control processes involved in task switching and all have used different task switching designs. For example, some studies used an alternate runs paradigm (Karayanidis et al., 2003; Lorist et al., 2000; Wylie et al., 2003) while others used an externally cued paradigm (Brass et al., 2005; Poulsen et al., 2005, 2001; Rushworth et al., 2002; Sinai and Phillips, 2002). Task set difficulty also varied, ranging from either simple classification tasks (e.g., categorising a number as either even or odd) to more complex tasks (e.g., categorising a word as either living or non-living). Finally, some task switching designs varied stimulus–response mappings rather than the tasks themselves (Rushworth et al., 2002). Although the studies cited above involve task switching, their designs were quite different, making it difficult to observe a consistent picture from their findings.

Nevertheless, two findings do appear to emerge from many of these studies. The first is the presence of a larger negative slow wave obtained over posterior scalp regions during the period preceding a repeat target, as opposed to a switch target. This is possibly a stimulus preceding negativity (SPN), which is believed to reflect the anticipatory activity sustained by a network involving thalamo-cortical pathways. According to Brunia and van Boxtel (2001), these pathways activate both frontal and parietal regions when preparing for a forewarned or predictable task. Brunia and van Boxtel (2001) argue that negativity observed at frontal scalp regions indexes the ongoing control exerted over attentive processes, while negativity observed over parietal regions indexes anticipation of task relevant stimuli. The posterior negativities observed prior to predictable task repetitions in the task switching studies reported above (Brass et al., 2005; Karayanidis et al., 2003; Lorist et al., 2000; Poulsen et al., 2005, 2001; Rushworth et al., 2002; Sinai and Phillips, 2002) suggest facilitated processing during repeat as opposed to switch trials. As for switch- and repeat-related frontal negativities, task switching studies have not provided consistent results. Some authors report larger frontal negativities on switch trials (Lorist et al., 2000; Poulsen et al., 2005, 2001) while others report large frontal negativities on repeat trials (Rushworth et al., 2002). Still others report no differences between the frontal negativities of repeat and switch trials despite posterior negativity differences (Karayanidis et al., 2003; Sinai and Phillips, 2002). It is not yet clear what can account for these discrepant findings but methodological differences among these studies are at least one probable cause. In spite of these differences, what is needed is a functional understanding of the negativities elicited during task preparation. We attempt to provide this in the present study by conducting within-subject analyses of the relationship between negative slow waves and the local switch cost when RT for repeat and switch trials are equated. That is, one of our goals was to determine whether the negative slow wave discriminates between repeat and switch trials. To do so, we compared repeat and switch trials equated