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Pre-stimulus EEG effects related to response speed, task switching and upcoming response hand

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Abstract

The task-switching paradigm provides an opportunity to study whether oscillatory relations in neuronal activity are involved in switching between and maintaining task sets. The EEG of subjects performing an alternating runs [Rogers, R.D., Monsell, S., 1995. Costs of a predictable switch between simple cognitive tasks. Journal of Experimental Psychology: General 124, 207–231] task-switching task was analyzed using event-related potentials, the lateralized readiness potential, instantaneous amplitude and the phase-locking value [Lachaux, J.P., Rodriguez, E., Martinirie, J., Varela, F.J., 1999. Measuring phase synchrony in brain signals. Human Brain Mapping 8, 194–208]. The two tasks differed in the relevant modality (visual versus auditory) and the hand with which responses were to be given. The mixture model [de Jong, R., 2000. An intention driven account of residual switch costs. In: Monsell, S., Driver, J. (Eds.), Attention and Performance XVII: Cognitive Control. MIT Press, Cambridge] was used to assign pre-stimulus switch probabilities to switch trials based on reaction time; these probabilities were used to create a fast–slow distinction between trials on both switch and hold trials. Results showed both time- and time–frequency-domain effects, during the intervals preceding stimuli, of switching versus maintenance, response speed of the upcoming stimulus, and response hand. Of potential importance for task-switching theory were interactions between reaction time by switch–hold trial type that were found for a frontal slow negative potential and the lateralized readiness potential during the response–stimulus interval, indicating that effective preparation for switch trials involves different anticipatory activity than for hold trials. Theta-band oscillatory activity during the pre-stimulus period was found to be higher when subsequent reaction times were shorter, but this response speed effect did not interact with trial type. The response hand of the upcoming task was associated with lateralization of pre-stimulus mu- and beta-band amplitude and, specifically for switch trials, beta-band phase locking.

Keywords: Task switching; Wavelet analysis; Hand; CNV; LRP; Theta; Beta

1. Introduction

Voluntary actions are characterized by a combination of flexibility and persistence (Goschke, 2003): responses to similar stimuli may change, as new intentions are formed, and responses to changing stimuli may remain constant, as goals are maintained over time and situations. The state of the brain that determines its response to different stimuli is described by the task set (Monsell, 2003), defined as the mapping of stimuli to responses. Under changing circumstances, either switching between different task sets or holding a task set may be required. Patients with prefrontal damage show a lack of control of flexibility in response to environmental demands (Barcelo and Knight, 2002; Milner, 1963). Such patients are able to set up stimulus–response mappings, but may fail to keep the task set active when confronted with distractions, or persevere in a task set when a switch is required, as in the Wisconsin card sorting test (Grant and Berg, 1948). The task-switching paradigm provides an opportunity to study the control of task sets.

The task-switching paradigm involves the presentation of sequences of trials that require either changing or maintaining task sets. The mean reaction time of trials for which subjects have to change task set is higher than that of trials requiring the same task set as the previous trial (Allport et al., 1994; Rogers and Monsell, 1995; Meiran, 1996). These switch costs can be reduced by increasing the length of the preparation interval, but they are still present at long intervals (Monsell, 2003). The

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persistent switch costs at long preparation intervals are called residual switch costs. Some form of interference due to a previously realized task set, such as task set inertia, a persisting bias of the previous task set (Allport et al., 1994), or the automatic retrieval of previously used specific stimulus–response associations (Wylie and Allport, 2000), is one way of explaining switch costs. The decay of the effect of previous task sets over time could explain the reduction of switch costs by increased preparation interval. Even if preparation for switch and hold trials involves the same mechanisms for preparation, the effect of decaying interference on these mechanisms could lead to an interaction of trial type and preparation interval on reaction time (Gilbert and Shallice, 2002). Another hypothesis explaining switch costs is that a time-consuming task set reconfiguration process is necessary to switch task sets, and that this process can be only partially completed prior to stimulus presentation (Rogers and Monsell, 1995). Decreased switch costs for longer preparation intervals would then reflect the completion of the initial, endogenous part of the reconfiguration process. Arguments for an anticipatory contribution to switch costs were provided by the findings that switch costs could be restricted to the first trial after a switch (Rogers and Monsell, 1995) and that when inter-trial interval (i.e., decay time) and cue–stimulus interval (preparation time) were disentangled, an increase in cue–stimulus interval was still found to reduce switch costs (Meiran, 1996). Even though by definition some kind of change in stimulus–response mapping must be initiated to allow a switch to occur, whether a switch-specific reconfiguration process must be assumed to underlie this switch would be hard to infer from data on switch costs (Gilbert and Shallice, 2002). Further, the retrieval of task-set goals, as opposed to subsequent reconfiguration, may play an important part in anticipatory processing (Koch, 2003; Mayr and Kliegl, 2003).

The distributions of reaction times supply further information on residual switch costs than only the means. In the mixture model of task switching, the distribution of the reaction times of long-interval switch trials is described as a mixture of two other reaction time distributions (de Jong, 2000). One is the short-interval switch distribution, with contains the longest reaction times: the influence of the previous task set is greatest in this condition, whether this is best described by strong inertia or the lack of time to initiate reconfiguration. The other is the long-interval hold condition, which contains generally fast responses. In this condition, the previous task set was already correct. A mixture of these two conditions' distributions can be used to model the condition containing residual switch costs, in the simplest case using a single parameter that specifies the proportion of trials from the fast, "no switch necessary" distribution. The residual switch cost is then due to the subset of trials from the slow distribution in which a switch is necessary but not made pre-stimulus. That is, in the mixture model, a subset of reaction times when subjects have to switch has the same, fast distribution of reaction times when switching is unnecessary.

The mixture model has been shown to provide good fits to data (de Jong et al., 1999; de Jong, 2000, 2001; Nieuwenhuis and Monsell, 2002). One explanation of the characteristic pattern of reaction time distributions is the failure to engage hypothesis (de Jong, 2000), which states that subjects intend to switch on most trials, but sometimes fail to engage the intention during the pre-stimulus interval, that is, to reconfigure their task set prior to stimulus presentation. In that case, their state at stimulus presentation is no better than when they were given only a short interval between trials. If they do successfully switch, on the other hand, they are as fast as when no switch was necessary at all at stimulus presentation, that is, as fast as hold trials under the same further conditions. Other explanations are of course possible: for instance, some form of proactive interference could be hypothesized to only occur on a certain proportion of trials. The mixture model does, nevertheless, open the possibility that despite persistent switch costs, full task-set reconfiguration may still be possible, pre-stimulus, on a subset of trials. Taking physiological data into account may help clarify the underlying causes of switch costs, and provide starting points to reduce the concepts of switching and holding tasks to specific physical and computational processes.

Psychophysiological studies of task switching have measured various aspects of the brain's behavior during cognitive control and task switching. fMRI studies have found prefrontal and parietal areas with increased activity during preparation for a switch (e.g. Sohn and Carlson, 2000; Braver et al., 2003; Derfuss et al., 2004). The event-related potential (ERP) has also been shown to be sensitive to brain activity associated with switching task sets. The ERP components that were of most interest to the present study were the contingent negative variation and lateralized readiness potential.

If preparation for a task switch involves an anticipatory switching process, and if this process can either occur or not as the failure to engage hypothesis suggests, then a reaction time by switch versus hold interaction would be expected to occur on slow negative potentials, as such potentials (i.e., the late contingent negative variation (CNV) (Leuthold et al., 2004; Mnatsakanian and Tarkka, 2002; Rosahl and Knight, 1995), readiness potential (Cui et al., 2000) and the stimulus-preceding negativity (SPN; Brunia, 1999)) appear to reflect processes that occur between a cue that indicates some form of cognitive action that must be performed in the future, and the point at which the action is expected to occur. Such future actions may involve either stimulus processing or motor responses (Brunia, 1999), and may be complex, e.g. the selection and maintenance of a cued part of a stimulus to be compared with another stimulus to be presented later (Mnatsakanian and Tarkka, 2002). A frontocentral increase in the CNV has also been found to increase with effort (Falkenstein et al., 2003). The term CNV will be used in the present paper to refer to such slow, pre-stimulus negative potentials. The lateralized readiness potential (LRP) (Coles, 1989; Leuthold et al., 2004) may also measure preparation of task sets, when the sets differ on which hand must be used to respond with. The LRP is a measure of the lateralization of the slow negative potential preceding a response, the contralateral motor cortex showing increased negativity. A pre-stimulus LRP occurs when specific muscle movements can be prepared