Fast dynamics of domain-general vs. specific neural mechanisms of task switching: Interactions between the frontoparietal and spatial orienting networks

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ABSTRACT

An important question in cognitive neuroscience is how the human brain self-organizes to perform tasks. Task switching involves the selection, inhibition and updating of hierarchically ordered task-set (sensory, sensorimotor, contextual, episodic) representations in our brains. A frontoparietal executive network is recruited during both proactive and reactive control of task-switching, although its interactions with an independent spatial orienting network have not been addressed yet. Frontoparietal activity is strongly associated with shifts of attention between locations (Corbetta et al., 2000). Likewise, frontoparietal activity is also observed in many different kinds of tasks (Peterse & Posner, 2012; Duncan, 2013), suggesting related mechanisms. The relative contributions from task-switch specific and domain-general mechanisms to the temporal dynamics of this frontoparietal network are still ill-defined. This study addressed these questions by measuring event-related potentials (ERPs) in three tasks with different cognitive demands, while manipulating involuntary spatial orienting.

PARTICIPANTS & METHODS

Nineteen young participants (four male, mean age 22,78; SD=1.6) were intermittently cued to switch or repeat their perceptual categorization of geometrical shapes varying in colour and form - Switch task, or else they performed two visually identical control tasks with lesser cognitive demands and distinct S-R mappings - Go/NoGo and Oddball task (Fig. 1). Spatial orienting was manipulated as a task-irrelevant factor, with visual stimuli presented either centrally or peripherally in two separate trial blocks, each with identical visual stimulation consisting of frequent coloured shapes (p=0.9) and randomly interspersed black shapes (p=0.1).

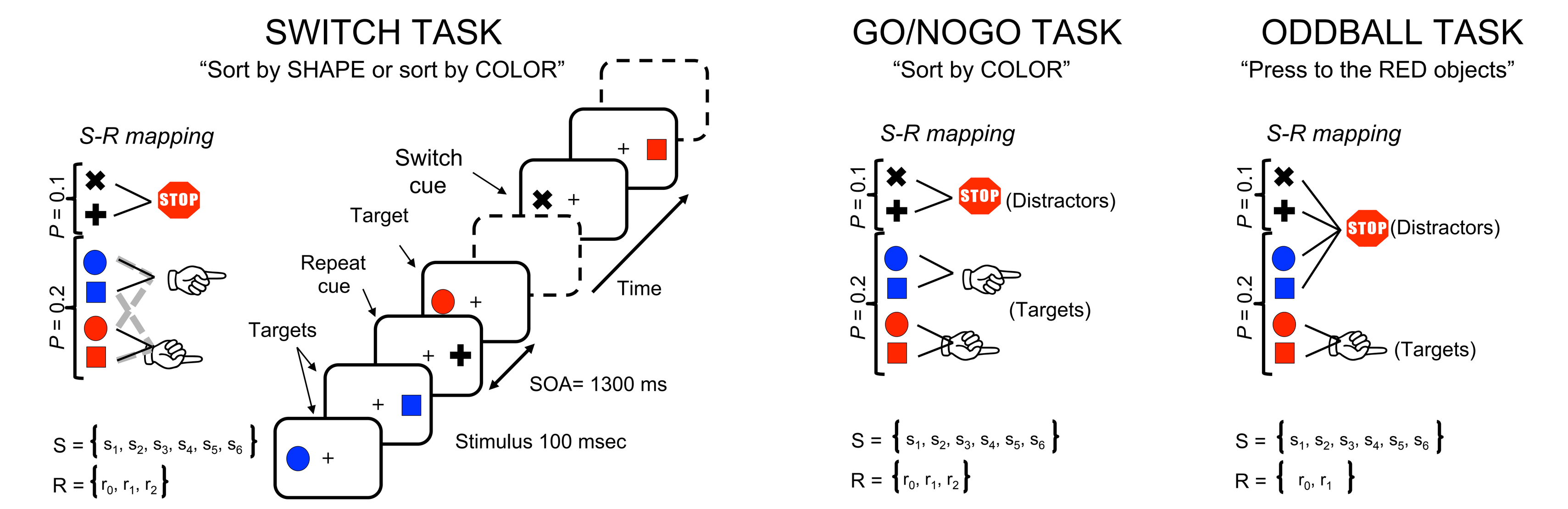
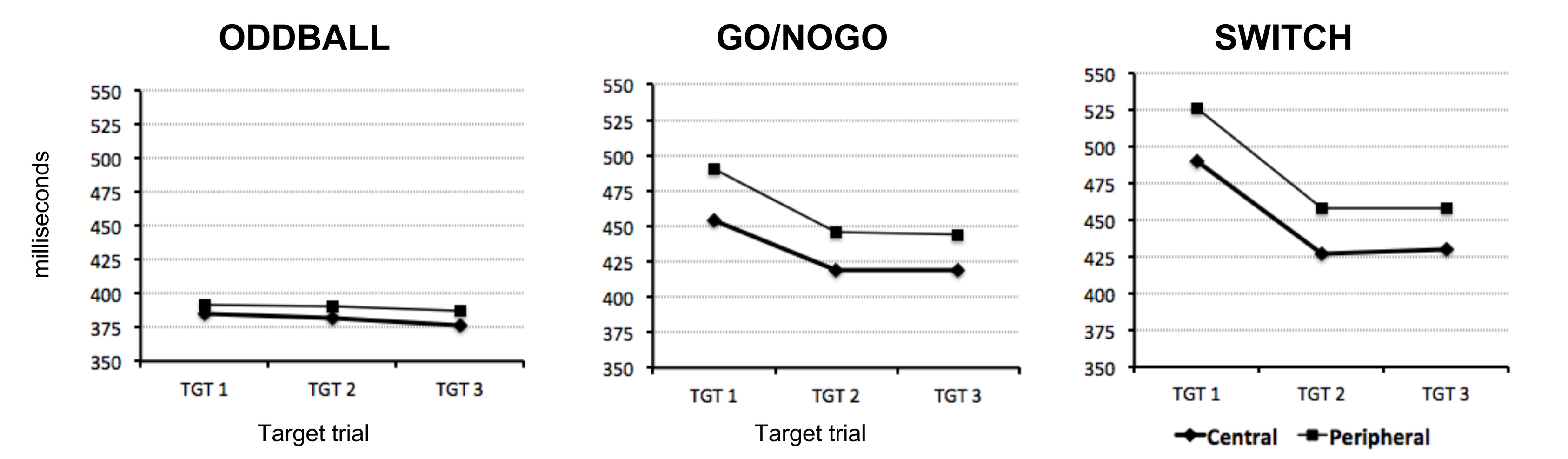


Figure 1. Novel bi-field visuomotor task. *Switch task*: participants are instructed to sort the same stimuli than in the control tasks according to two classification rules that alternate following the cues. *Go/NoGo task*: similar perceptual load but higher sensorimotor demands while responding to two stimuli and withholding responses to NoGo distractors. *Oddball task*: participants pressed one button to designated stimuli while ignoring all other stimuli (Barceló et al 2008).

BEHAVIOUR



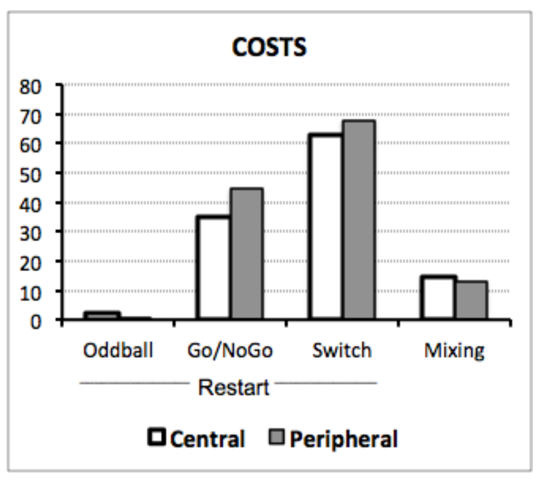


Figure 2. Mean reaction times (RTs) yielded main effects for Task (p<0.0001), Spatial location (p<0.001), and Trial (p<0.0001), with the longest RTs for the Switch task, peripheral locations and 1st target trials. A Task x 'Spatial location' interaction (p<0.05) revealed longer RTs for peripheral locations in the Switch and Go/NoGo tasks, but not the Oddball task. A Task x Trial interaction (p<0.001), revealed the presence of restart costs in Switch and Go/NoGo tasks, but not in the Oddball task. No other effects or interactions reached significance for mean RTs The analysis of behavioral costs revealed: (1) local switch costs did not differ significantly from zero in the Switch task; (2) restart costs differed significantly across tasks (p<0.0001), but none of these were modulated by Spatial location (F's<1); (3) mixing costs were present in the Switch task (p<0.0001), but were not influenced by the hemifield of Spatial location (F<1).

ELECTROPHYSIOLOGY

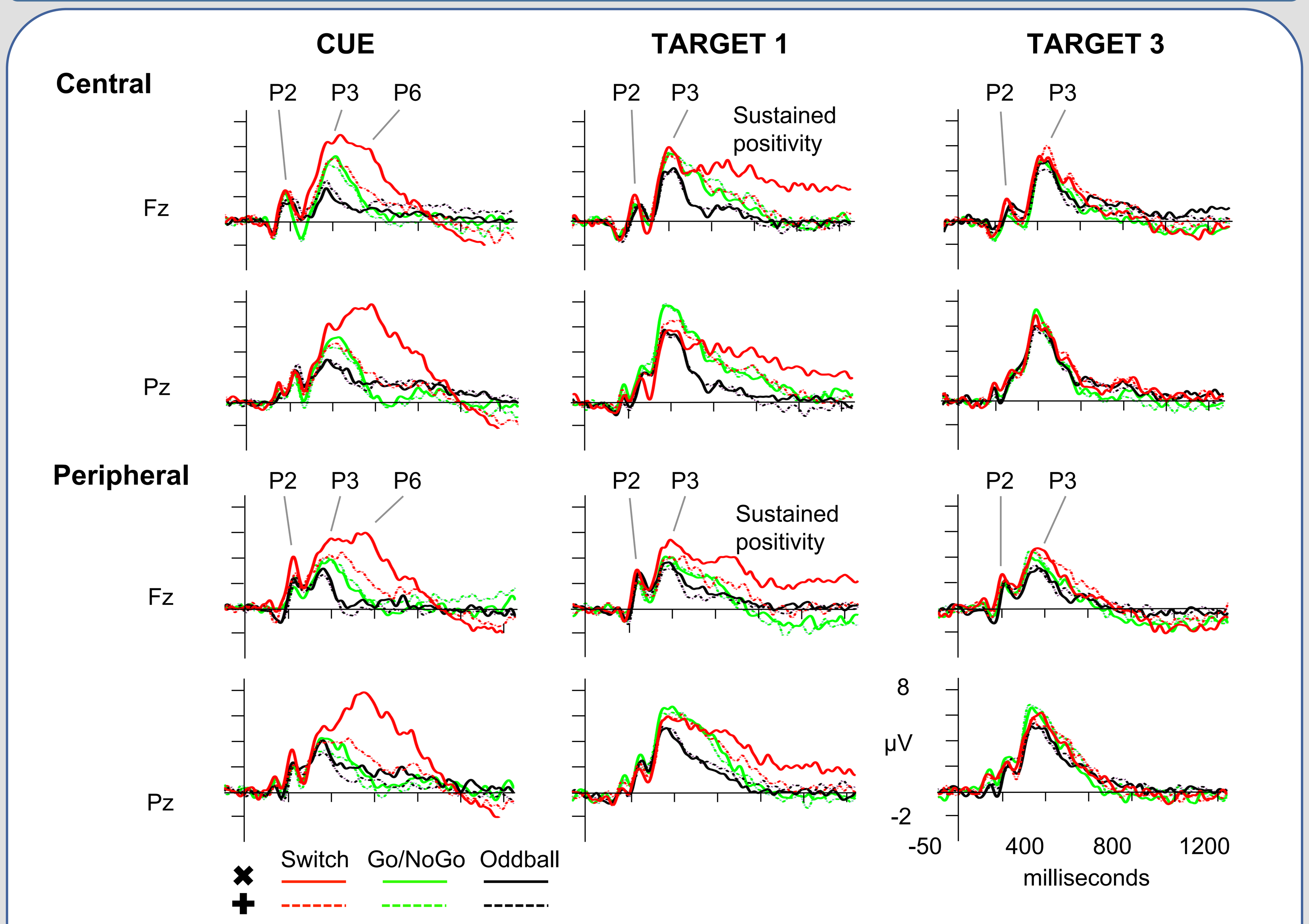


Figure 3. ERP waveforms at Fz and Pz in response to cues and targets 1st and 3rd corresponding to the central and peripheral display. Cue-locked P3 amplitudes were larger for central presentation (p<0.026), and also larger for the Go/NoGo and Switch tasks as compared to the Oddball task (p's<0.013). Additionally, switch cues evoked larger P3s than repeat cues only in the Switch task (p's<0.025). A P6 component was observed only in response to switch cues in the Switch task (p's<0.0001). A CNV was more pronounced in the Switch than in the other two tasks (p's<0.005). Neither P6 nor CNV were influenced by spatial location. First target P3 amplitudes were enhanced for the Switch and Go/NoGo tasks as compared to Oddball (p's<0.048). Finally, in the Switch task a sustained positivity was locked to 1st targets but was absent in 3rd target trials. This target-locked positivity was not affected by Spatial location of the stimuli.

SCALP TOPOGRAPHY

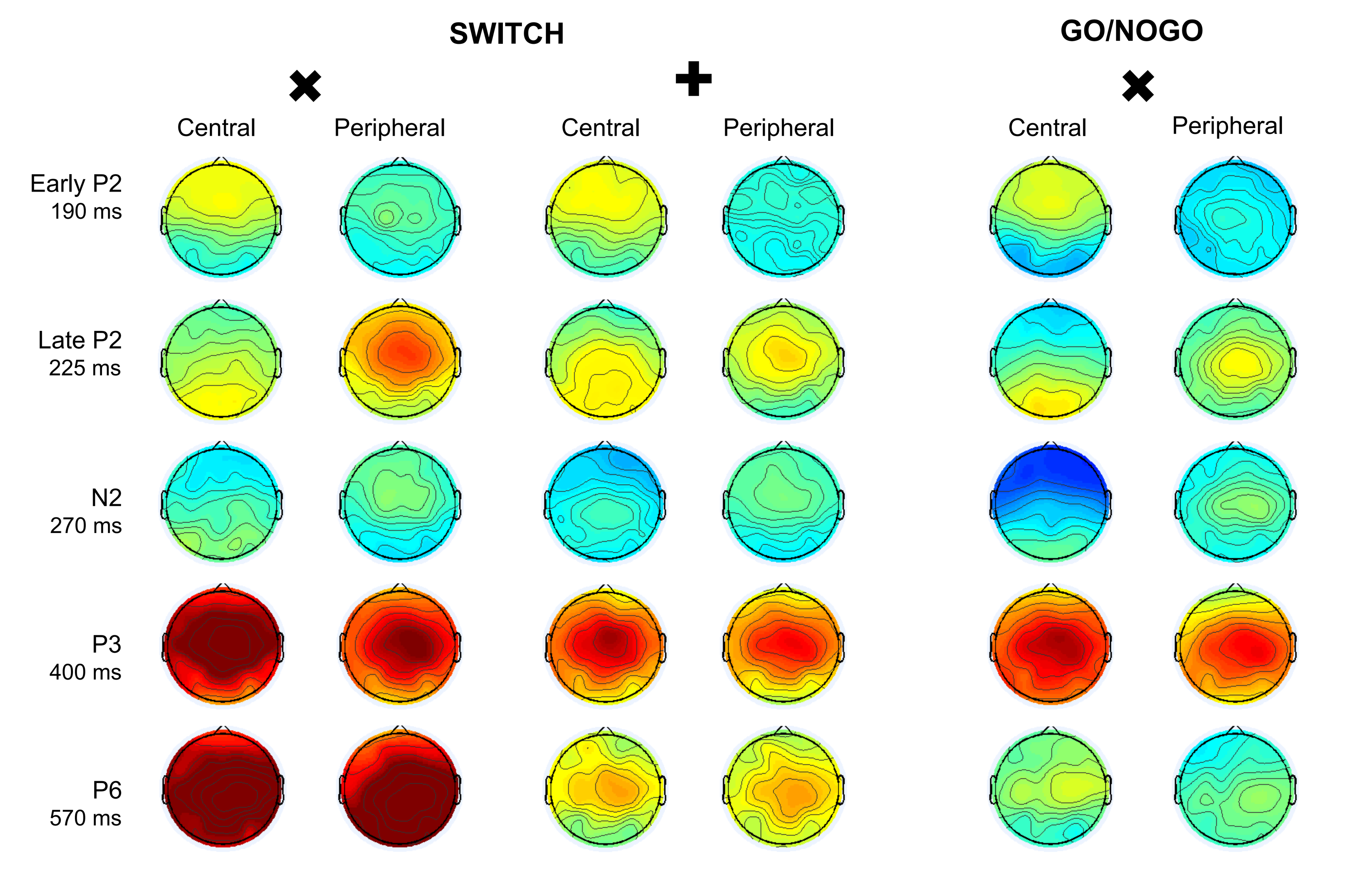


Figure 4. Topographical maps for the cue-locked P2, N2, P3 and P6 components in the Switch and Go/NoGo tasks. The latency and scalp distribution of P2 was modulated by Spatial location in both tasks: While for central displays cue P2 peaked at 190 ms frontally and at 225 ms parieto-occipitally, it showed a unique fronto-central 225 ms peak for peripheral stimuli. With regards to N2, central displays elicited a more frontal distribution than peripheral displays. In the Switch task, switch cues evoked larger P3 (p's<0.025) and P6 (p's<0.001) amplitudes than repeat cues, although the scalp distributions of these two components were not influenced by the Spatial location of stimuli.

ERP RESULTS: SWITCH TASK

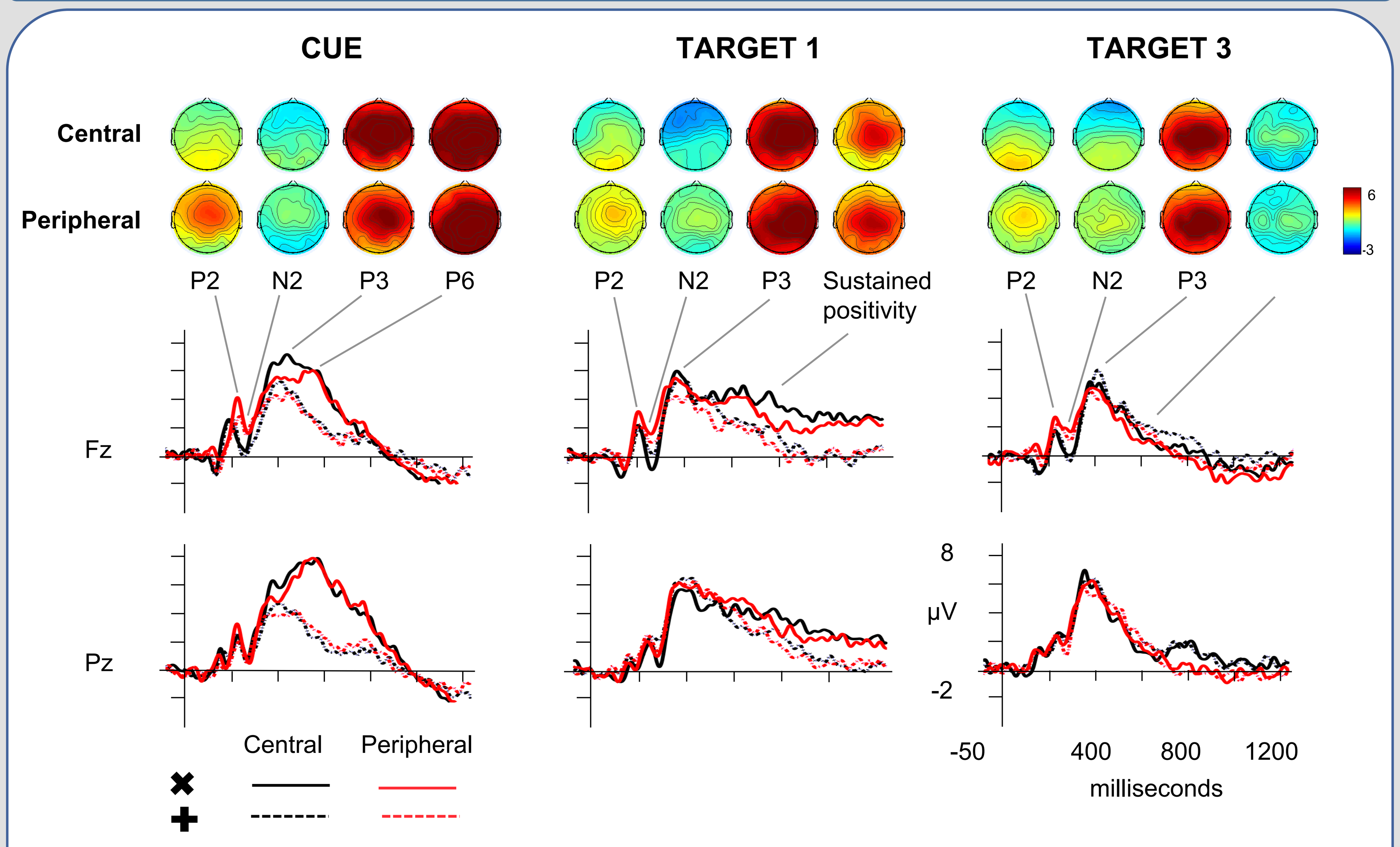


Figure 5. ERP waveforms and topographic maps in the Switch task. Main effects of 'Spatial location' were present for cue-locked P2, N2 and P3 amplitudes (p's<0.026), but not for cue-locked P6 and CNV components. The 3-way interaction between 'Component', 'Spatial location' and 'Cue type' revealed that cue-locked P2 was enhanced in response to switch as compared to repeat cues, but only for peripheral cues (p<0.001), whereas cue-locked P3 and P6 were larger in response to switch than repeat cues regardless of 'Spatial location' (p's<0.025). The CNV was not modulated by 'Cue type' nor 'Spatial location'. Target-locked P2 amplitudes in response to the 1st target were larger for peripheral stimuli (p<0.001), while N2 amplitudes were more pronounced for central displays (p<0.013). First target N2 was more pronounced for switch compared to repeat trials but only for central display (p<0.05). Neither 1st target P3 nor the sustained positivity were influenced by 'Spatial location', although both components were larger following a switch than a repeat cue (p's<0.0001), mostly over frontopolar and frontal scalp regions. As for 3rd targets no significant main effects nor interactions were observed for late ERP waveforms.

CONCLUSIONS

- Both switch-specific (indexed by cue-locked P6 and a sustained target-locked positivity following task transitions) and domain-general mechanisms (indexed by cue- and target-locked P2 and P3 components) suggest fast recurrent neural activations within a common frontoparietal network.
- The modulations in cue-locked P2, N2 and P3 reflect the interaction between spatial orienting and cognitive control. Specifically, enhanced switch cue-locked P2 seem to reflect early executive control of task switching in the face of higher spatial uncertainty.
- Spatial orienting to the first target influenced early indexes of attentional control, as shown by the modulations observed in P2 and N2 amplitudes.
- The distinct influence of spatial orienting upon cue-locked P3 and target P3 add to the discussion of the P300 family and their functional role in the proactive and reactive control of task switching.
- All in all, these results reveal distinct spatiotemporal interactions between the frontoparietal and spatial orienting networks, and shed new light on the functional role of a frontoparietal "multiple demand" system (Duncan, 2013) during the preparation and implementation stages of task switching.

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