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Functional characteristics of control adaptation in intermodal sensory processing

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ABSTRACT

The present work investigated functional characteristics of control adjustments in intermodal sensory processing. Subjects performed an interference task that involved simultaneously presented visual and auditory stimuli which were either congruent or incongruent with respect to their response mappings. In two experiments, trial-by-trial sequential congruency effects were analysed for specific conditions that allowed ruling out "non-executive" contributions of stimulus or response priming to the respective RT fluctuations. In Experiment 1, conflict adaptation was observed in an oddball condition in which interference emanates from a task-irrelevant and response-neutral low-frequency stimulus. This finding characterizes intermodal control adjustments to be based – at least partly – on increased sensory selectivity, which is able to improve performance in any kind of interference condition which shares the same or overlapping attentional requirements. In order to further specify this attentional mechanism, Experiment 2 defined analogous conflict adaptation effects in non-interference unimodal trials in which just one of the two stimulus modalities was presented. Conflict adaptation effects in unimodal trials exclusively occurred for unimodal task-switch trials but not for otherwise equivalent task repetition trials, which suggests that the observed conflict-triggered control adjustments mainly consist of increased distractor inhibition (i.e., down-regulation of task-irrelevant information), while attributing a negligible role to target amplification (i.e., enhancement of task-relevant information) in this setup. This behavioral study yields a promising operational basis for subsequent neuroimaging investigations to define brain activations and connectivities which underlie the adaptive control of attentional selection.

1. General introduction

1.1. Top-down attentional control: scope and experimental investigation

Top-down attentional control (TAC), i.e., the purposeful selection of relevant over irrelevant sensory information, is an essential prerequisite of goal-directed action and hence a main instance of executive control. Accordingly, TAC has been intensively investigated in both cognitive psychology and non-clinical cognitive neuroscience (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gruber & Goschke, 2004; Kiesel et al., 2010; Maunsell & Treue, 2006; Treue, 2001). Moreover, deficits in this domain may represent a direct expression of neuropathophysiological processes, which renders TAC an important issue for clinical neuroscience, too (e.g., Melcher, Falkai, & Gruber, 2008). In the latter context, attentional dysfunctions are among the most promising candidate *endophenotypic markers* (Gottesman & Gould, 2003) for psychiatric disorders such as schizophrenia (Cornblatt & Malhotra, 2001; Pinkham, Gur, & Gur, 2007; Snitz, MacDonald, & Carter, 2006; Turetsky et al., 2007) and bipolar disorder (Clark & Goodwin, 2004; Kurtz & Gerraty, 2009; Langenecker, Saunders, Kade, Ransom, & McInnis, 2010; Pattanayak, Sagar, & Mehta, 2011).

The functioning and neural implementation of TAC can be investigated by means of two basic groups of task paradigms: Attentional cueing tasks on the one hand and conflict or interference tasks on the other hand. In *attentional cueing tasks*, subjects

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are explicitly instructed by a *cue* stimulus to orient attention to a specific location, sensory dimension or modality prior to the appearance of the target stimulus proper (Corbetta & Shulman, 2002; Posner, Walker, Friedrich, & Rafal, 1984). Cueing paradigms allow investigating behavioral benefits and costs in target processing after valid cues and invalid cues, respectively. Moreover, measuring brain responses to attentional cues provides a straightforward strategy to investigate neural implementations of TAC and has led to the description of *frontoparietal attention networks* (for review see Corbetta & Shulman, 2002).

By contrast, *conflict* or *interference tasks* like the Stroop task (Stroop, 1935), the Simon task (Simon, 1969), the Flanker task (Eriksen & Eriksen, 1974), and the task-switching paradigm (Kiesel et al., 2010; Monsell, 2003), subjects are presented with multivalent stimuli. The different stimulus aspects may be mapped to different competing responses at times (incongruent stimuli) and thereby induce competition requiring increased top-down control to select the relevant over the irrelevant aspects. Accordingly, brain activations related to competition trials are widely interpreted as neural substrate of attentional control (Kerns et al., 2004). This interpretation, however, is restricted by the fact that contrast analyses between competition conditions and non-competition baseline conditions intermingle at least two processes: the occurrence or detection of competition on the one hand and remediate executive efforts on the other. This functional dissociation is a central postulate of the prominent *conflict monitoring account* (Botvinick et al., 2001), wherein activation in the anterior cingulate cortex is construed as neural substrate of conflict monitoring (i.e., the detection of conflict or competition) and subsequent activation in the dorsolateral prefrontal cortex is construed as the neural substrate of implemented selective control. This neurofunctional distinction of complementary evaluative (i.e., monitoring) and executive sub-processes provides a plausible conceptualization of cognitive control, not as singular instance but rather as a continuous, dynamic and adaptive process (Scherbaum, Dshemuchadse, Fischer, & Goschke, 2010). At the same time, this conceptualization stresses that the investigation of attentional control in interference processing may undesirably confound genuine executive processes with other evaluative processes. The *conflict adaptation principle* – a direct derivate of conflict monitoring theory – yields an experimental strategy to circumvent the described confound.

1.2. The conflict adaptation principle (and its challenges)

The conflict adaptation principle basically yields that top-down control is strengthened after the occurrence of conflict (Botvinick et al., 2001; Kerns, 2006; Kerns et al., 2004; Rabbitt, 1966; Rabbitt, 1968; Ullsperger, Bylsma, & Botvinick, 2005). The basic experimental demonstration of conflict adaptation is the so-called Gratton-effect (Gratton, Coles, & Donchin, 1992), which describes decreased or even absent behavioral conflict effects after conflict trials as compared to when trials without conflict preced. This sequential effect (Egner & Hirsch, 2005; Kerns et al., 2004) is statistically described as interaction between current and preceding congruency of relevant and irrelevant information and has been observed in a variety of different tasks (e.g., Egner, Ely, & Grinband, 2010; Kunde & Wühr, 2006; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Pfister, Schroeder, & Kunde, 2013; Ullsperger et al., 2005). Most importantly, the interpretation of sequential effects as reflecting "control exertion" is challenged by different alternative explanations which describe the Gratton effect as emanating from "passive" sensory priming rather than (pro-)active control adaptation (see Egner, 2007, for a review). First, conflict reduction after incongruent trials may reflect repetition priming in some settings due to stimulus-response repetitions which facilitate responding (Mayr, Awh, & Laurey, 2003). For this reason, prior studies have adjusted their data for stimulus repetitions (cf. Egner & Hirsch, 2005; Kerns et al., 2004), which, however, partly leads to an undesirable imbalance regarding response repetitions between the compared sequence conditions (cf. Nieuwenhuis et al., 2006). Another challenge of the control adaptation principle is yielded by Feature Integration Theory (Hommel, Proctor, & Vu, 2004), which explains performance decrements for trial sequences with congruency switches between trials (congruent following incongruent, IC, and vice versa, CI) by incompatible response priming when stimulus features of the preceding trial are repeated in one stimulus dimension and changed in another. Stimuli including a repetition of just one stimulus feature, according to the theory, provoke 'partial repetition costs' because they prime both a response repetition and a response alternation simultaneously. Trial sequences with congruency repetitions (II and CC trials), on the other hand, include either complete stimulus repetitions which necessarily imply a response repetition (leading to repetition priming) or complete stimulus alternations that typically also call for a response alternation so that in either case both stimulus dimensions prime the required response.

1.3. Goals and scope of the present investigations

To date, a considerable number of studies using a wide range of tasks and stimuli have demonstrated conflict adaptation effects (i.e., interference reduction after interference trials) occurring independent of sensory priming processes (e.g., Kim & Cho, 2014; Notebaert & Verguts, 2007; Schmidt & Weissman, 2014). Therefore, there is substantial evidence that control efforts are indeed adapted (i.e., increased) after interference or conflict trials, at least when certain experimental preconditions are met (cf. Freitas & Clark, 2014; Weissman, Jiang, & Egner, 2014; but see Cho, Orr, Cohen, & Carter, 2009; Puccioni & Vallesi, 2012; Schmidt, 2013; Schmidt & De Houwer, 2011). This basically opens the possibility to adopt interference task paradigms in functional neuroimaging to define control-related brain activations by the analyses of sequential effects (cf. Egner & Hirsch, 2005). However, the specific functional characteristics of control adaptation after interference processing are still not sufficiently understood. In the present work, we therefore wanted to demonstrate Gratton-like sequential effects in an intermodal interference paradigm which cannot be explained by priming effects and therefore most probably reflect control adaptation. On this basis, we sought to elucidate the functional characteristics of control adaptation in a multimodal setting to answer the following two questions:

(1) *How general is intermodal control adaptation?* More specifically, are control increases following conflict processing suited to improve performance in interference conditions different from the specific condition that triggered control adaptation. Prior studies exclusively observed adaptation effects between equivalent conflict or interference conditions within the same task (e.g., Hommel et al., 2004; Schmidt & Weissman, 2014) or between analogous conflict conditions of different task paradigms (e.g., Egner, Delano, & Hirsch, 2007; Freitas & Clark, 2014). If control adaptation indeed leads to a strengthening of attentional selectivity, this should also improve performance in different interference conditions which share the same or overlapping attentional requirements.

(2) *How specific is intermodal control adaptation?* Generally, one can distinguish two basic sub-processes to exert top-down attentional control: the amplification of task-relevant information and the inhibition of task-irrelevant information. In this context, the question suggests itself as to whether