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Research Report

The interaction of task-relevant and task-irrelevant stimulus features in the number/size congruency paradigm: An ERP study

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ABSTRACT

We studied whether task-relevant numerical information and task-irrelevant physical size information interact during perceptual and/or response processing in the number/size congruency paradigm (NSCP). Participants decided which of two simultaneously presented numbers was larger numerically. The physical size of numbers delivered neutral, congruent, or incongruent information with numerical magnitude. Both stimulus- and response-locked event-related brain potentials (ERPs) were analyzed. The lateralized readiness potential (LRP) was used for indexing motor preparation. Similar early facilitation and interference effects appeared in the amplitude of ERPs between 150 and 250 ms after stimulus presentation, focused over parieto-occipital electrode-sites. We conclude that these effects reflected a similar process in both facilitation and interference, related to a general increase of processing load and/or conflict detection. Further, we have replicated our former findings demonstrating late facilitation and interference effects between 300 and 430 ms. These effects may be related to the conflict monitoring and response-selection activity of the anterior cingulate cortex, or may be related to higher level contextual analysis. Our findings suggest that facilitation and interference effects appear at multiple levels of stimulus and response processing. We have also demonstrated ERP amplitude effects as a function of numerical difference between the to-be-compared numbers both in stimulus- and response-locked ERPs.

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1. Introduction

It is a major question how perceptual and response processes initiated by parallel processed task-relevant and task-irrelevant stimulus features interact with each other during cognitive processing. The number/size congruency paradigm (NSCP) provides a means to investigate this question. In the NSCP participants decide which one of two simultaneously presented Arabic digits is larger than the other one either in numerical magnitude or in physical size (Henik and Tzelgov, 1982; Duncan and McFarland, 1980). The relationship of numerical and physical size features of the digits may be neutral, congruent, or

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Abbreviations: ACC, Anterior cingulate cortex; ANOVA, Analysis of variance; ERP, Event-related potential; fMRI, Functional magnetic resonance imaging; IPS, Horizontal intraparietal sulci; LRP, Lateralized readiness potential; NSCP, Number/size congruency paradigm; SNARC, Spatial–numerical association of response codes

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incongruent. In the congruent condition the numerically larger digit is physically larger than the other digit (e.g. which is larger numerically? 2 or **9**?). In the incongruent condition the numerically larger digit is physically smaller than the other one (e.g. which is larger numerically? **2** or 9?). In the neutral condition the digits do not differ on the task-irrelevant stimulus dimension (e.g. which is larger numerically? 2 or 9?). The RT is faster in the congruent condition than in the neutral condition, and the RT is slower in the incongruent condition than in the neutral condition. The speed-up of RT in the congruent condition relative to the neutral condition is called facilitation. The slowing of the RT in the incongruent condition relative to the neutral condition is called interference. The phenomena of facilitation and interference attest that the task-irrelevant stimulus feature is processed automatically and in parallel with the task-relevant feature (Henik and Tzelgov, 1982). However, it is an open question whether task-relevant and task-irrelevant features interact during perceptual and/or response processing. In order to examine this issue we have investigated the timing of facilitation and interference effects in the NSCP.

According to the continuous flow model of Eriksen and Schultz (1979) stimulus processing can be roughly subdivided into temporally overlapping perceptual and response organization phases. These processing phases do not follow each other in a perfectly serial fashion (Sternerg, 1969). Rather, perceptual processes influence response activity in a continuous fashion even before the final completion of stimulus analysis: According to the continuous flow model information about the stimuli accumulates gradually during perceptual processing. As soon as the gradual perceptual processing of the stimuli reaches a certain degree, perceptual processes begin to influence response activity. Therefore even partially processed stimulus information can affect response activity. The more advanced the perceptual processing of stimulus features, the more they will influence response activity. An overt behavioural response is produced when the activation level of a certain response exceeds a criterion (Eriksen and Schultz, 1979; Smid et al., 1990; Eriksen et al., 1985; Coles et al., 1985; Gratton et al., 1988). Within the context of the continuous flow model stimulus features can interact with each other during the course of either perceptual or response processing.

Considering the above model, numerical and size information can be thought to interact with each other during the perceptual and/or the response phase of the NSCP. Facilitation and interference effects result from these interactions. On the one hand, perceptual level interactions would suggest that stimulus features interact with each other at the level of stimulus representations (Hock and Egeth, 1970). On the other hand, interactions may also happen during the response phase. One possible explanation of interference during the response phase is that interactions are related to motor processes. This explanation assumes that the parallel processed numerical and physical size information compete with each other in order to dominate response activity (Morton and Chambers, 1973; Posner and Snyder, 1975). Facilitation and interference processes then result from motor facilitation/competition between the response processes initiated by task-relevant and task-irrelevant information. Another possibility is that response-phase facilitation/interference result from the interaction of complex and slow stimulus analysis processes (e.g. decisions about stimulus categories).

The high temporal resolution of event-related brain potentials (ERPs) offers a chance to determine whether facilitation and interference effects happen during perceptual or response processing. First, facilitation and interference effects in the amplitude of ERPs can reveal the onset and duration of facilitation and interference effects. Second, the so-called lateralized readiness potential (LRP) is able to track the onset of motor preparation. The LRP is a measure of motor cortex activation, and it indicates selective motor preparation and response initiation before an overt response is given (Gratton et al., 1988; De Jong et al., 1988). According to the conventional computation of the LRP a significant negative LRP deflection reflects a correct response tendency whereas a significant positive LRP deflection reflects an incorrect response tendency. A significant deviation of the LRP from the baseline suggests that motor preparation has begun. Therefore in the context of the continuous flow model (Eriksen and Schultz, 1979) the LRP can be used to determine the time point when enough perceptual information has been accumulated and the influencing of motor processing has begun. This, in turn, allows for the dissociation of cognitive processes happening during the perceptual and response phases.

Using the above approach, in a recent ERP study of the NSCP (Szűcs and Soltész, 2007) we analyzed the timing of facilitation and interference effects in the amplitude of ERPs, and we have also monitored LRP effects. Contrasting the congruent and neutral conditions we found that numerical decisions were facilitated by task-irrelevant physical size information. Contrasting the incongruent and neutral conditions we found that numerical decisions interfered with task-irrelevant physical size information. One facilitation effect appeared in the amplitude of ERPs before the onset of motor preparation between 140 and 240 ms, another facilitation effect appeared after the onset of motor preparation between 280 and 320 ms. In contrast, ERP interference effects appeared only after the onset of motor preparation between 330–460 and 550–660 ms. Therefore we concluded that facilitation appeared during both the perceptual (early) and response processing (late) phases, whereas interference appeared solely during the response processing phase.

Late facilitation and interference effects in the amplitude of ERPs in our previous data were in agreement with the first study of the NSCP (Schwarz and Heinze, 1998) and with a recent study published after the initial submission of the current article (Cohen-Kadosh et al., 2007). The study of Schwarz and Heinze (1998) used 6 recording electrodes, reported data on 2 electrodes, and contrasted the congruent and incongruent conditions (congruency effect) of the NSCP (Schwarz and Heinze, 1998). This study reported a congruency effect beginning from 368 ms post-stimulus in the numerical comparison task. This congruency effect appeared after the LRP had deviated from baseline (at 240 ms). Schwarz and Heinze (1998) wished to decide between the early and late interaction explanations by expecting that late interaction would be suggested *especially* by the following observations (bottom of page 1170): (1) There are *no* congruity effects in early difference potentials (their point b.i.). (2) The faster processed irrelevant stimulus dimension causes initial incorrect response activation measured by the LRP (their point b.ii). *No* early congruity effects were observed in the amplitude of ERPs (observing such

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