

## Comparison of two Simon tasks: Neuronal correlates of conflict resolution based on coherent motion perception

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The present study aimed at characterizing the neural correlates of conflict resolution in two variations of the Simon effect. We introduced two different Simon tasks where subjects had to identify shapes on the basis of form-from-motion perception (FFMo) within a randomly moving dot field, while (1) motion direction (motion-based Simon task) or (2) stimulus location (location-based Simon task) had to be ignored. Behavioral data revealed that both types of Simon tasks induced highly significant interference effects. Using event-related fMRI, we could demonstrate that both tasks share a common cluster of activated brain regions during conflict resolution (pre-supplementary motor area (pre-SMA), superior parietal lobule (SPL), and cuneus) but also show task-specific activation patterns (left superior temporal cortex in the motion-based, and the left fusiform gyrus in the location-based Simon task). Although motion-based and location-based Simon tasks are conceptually very similar (Type 3 stimulus–response ensembles according to the taxonomy of [Kornblum, S., Stevens, G. (2002). Sequential effects of dimensional overlap: findings and issues. In: Prinz, W., Hommel, B. (Eds.), *Common mechanism in perception and action*. Oxford University Press, Oxford, pp. 9–54]) conflict resolution in both tasks results in the activation of different task-specific regions probably related to the different sources of task-irrelevant information. Furthermore, the present data give evidence those task-specific regions are most likely to detect the relationship between task-relevant and task-irrelevant information.

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### Introduction

The Simon task has been widely used to study conflict resolution in cognitive psychology (Simon, 1969). When stimulus and response sides (right/left) do not correspond even though stimulus location is task-irrelevant, the resulting increase in reaction time (RT) is referred to as the Simon effect. This robust phenomenon is interpreted as resulting from the automatic generation of a spatial code in response to stimulus location. Since the spatial code overlaps with the relevant response code derived from the nonspatial dimension (e.g., shape), it interferes with the speed of correct response selection. The Dimensional Overlap (DO) model by Kornblum (e.g., Kornblum and Stevens, 2002) provides a theoretical framework to differentiate between the various conflict effects. It accounts for stimulus–stimulus (S–S) and stimulus–response (S–R) compatibility effects based on perceptual, conceptual or structural similarity between the relevant and the irrelevant stimulus dimensions on one side, and the response dimension of the task on the other side. According to the DO model, the Simon effect results from a direct stimulus–response conflict induced by a prepotent association between the stimulus and a response on the same side (Type 3 stimulus–response ensemble).

Although advances in neuroimaging methods over the past decade have opened new windows into human cognitive functions, the neural mechanism of cognitive control processes underlying experimental procedures, such as the Simon, Stroop, or Eriksen flanker tasks, remains largely unexplained. Up to now, only few studies compared in some detail neural networks activated by different conflict tasks within the same experimental session with event-related fMRI (Fan et al., 2003; Liu et al., 2004; Peterson et al., 2002; Wager et al., 2005). These studies reported numerous brain regions being activated during the conflict task condition as compared to the no-conflict task condition. Among these are the posterior frontomedian cortex (pFMC; in particular the anterior cingulate cortex (ACC), the pre-supplementary and the supplementary motor areas (pre-SMA/SMA)), the middle frontal cortex, the anterior insula/frontal operculum, anterior prefrontal, superior and

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inferior parietal cortices, as well as posterior areas. According to the conflict monitoring theory by Botvinick et al. (2004), it is the dorsal ACC (in particular the posterior rostral cingulate zone (rCZp) as defined by Picard and Strick (2001)) that responds to the occurrence of conflict. This area is supposed to trigger strategic adjustments, which serve to reduce conflict in subsequent performance. Corroborating this issue, Barch et al. (2001) presented data from a meta-analysis that clearly demonstrated the posterior rostral cingulate zone (rCZp; 3, 19, 35) to be involved in conflict resolution.

In order to test the hypothesis of a common neural network of conflict resolution, some recent fMRI studies compared different conflict tasks, such as Simon, Stroop, and Eriksen flanker task. Peterson et al. (2002) reported remarkably similar activation patterns during interference resolution in both the Stroop and the Simon tasks which overlapped in the ACC, SMA, visual association cortex, dorsolateral prefrontal cortex (dlPFC), caudate nuclei, as well as in inferior temporal, parietal, and frontal cortex. Although extent and magnitude of regional activations across tasks varied slightly, Peterson and colleagues suggested that the underlying neural processes associated with conflict resolution are very similar, though obviously not identical with respect to differing stimulus features between tasks. This study, however, was criticized by Liu et al. (2004) stating that the experimental design implicated an overlap of relevant and irrelevant stimulus dimensions, which is the main feature discriminating between the Simon and Stroop effects (Kornblum and Stevens, 2002). In order to control for stimulus attributes, Liu et al. (2004) introduced an experimental procedure incorporating both types of Stroop and Simon tasks and reported a common cluster of brain regions being activated by both tasks, but also task-specific brain regions.

Fan et al. (2003) conducted an fMRI experiment with three conflict tasks (color–word Stroop, Simon, and Eriksen flanker tasks) within the same group of participants in search for a common network for conflict resolution. They found significant activations in the ACC and left prefrontal cortex in all three conflict tasks but also additional areas that were exclusively activated in each task. Based on these data, the authors stated that not a single unified network, but distinguishable task-specific networks might underlie conflict processing. All three tasks, however, consisted of very different stimuli: color words in the Stroop task, color drawings of generic cartoon characters or objects in the Simon task, and a row of arrows in the Eriksen flanker task. The neuronal activation pattern derived from that study, therefore, reflected a possible confound of different task attributes and response selection mechanisms.

The aim of the present study was to analyze conflict resolution induced by two Simon tasks which only differed with respect to the source of conflicting information and thus avoiding individually differing recruitments of brain mechanisms of interference resolution due to different tasks. In order to comply with this experimental precondition, we introduced a task design where subjects had to identify shapes on the basis of form-from-motion perception (FFMo) within a randomly moving dot field, while (1) motion direction (motion-based Simon) or (2) stimulus location (location-based Simon) had to be ignored. Forms were defined only by coherent dot motion against stochastic background motion, without any static form cues. Most recently, Bosbach et al. (2004a, b) investigated the relation between high-level motion perception and action by conducting experiments in which the direction of motion was the irrelevant dimension, while the position of the stimuli was constant over time. The authors reported that (1) motion detection and motion processing may be independent of spatial position, and

(2) a significant Simon effect might be induced by dynamic stimuli that do not allow for relative position coding. If a single neural network is engaged in conflict resolution based on the two variants of a type 3 stimulus–response ensembles (Kornblum and Stevens, 2002), then the activation patterns of response conflict induced by both motion direction and stimulus location should only differ with respect to the specific demands related to the processing of different types of incompatible information.

## Materials and methods

### Subjects

Twenty healthy subjects (3 male, range 21–31 years, mean age: 25.5 years) participated in the study. None of the participants had a history of neurological or psychiatric disorders nor substance abuse or dependence. Each subject gave informed and written consent and was paid 10 € for participation. The study was approved by the local ethics committee.

### Experimental procedure: stimuli and tasks

Subjects had to detect and identify form-from-motion stimuli in two different experiments which were conducted within one session. The stimuli consisted of either a triangle or a square containing approximately 200 coherently moving bright dots on a dark screen against a randomly moving background of a total of 4000 dots. Both stimuli comprised the same area and number of dots. At the start of each trial, both a red fixation point and the stimulus were presented for a fixed period of 700 ms. Each press of the response button changed the color of the fixation point from red to white, thus providing a feedback signal that a response had been registered. During an interstimulus interval which was randomly jittered between 700 and 1300 ms, only a red fixation point remained on a homogeneous dark background.

### Motion-based Simon task

The motion-based Simon task contained three conditions: (1) compatible trials (COMP) consisted of dots moving coherently to the side corresponding to a correct response (e.g., a triangle requires a right-hand button press and all dots within the triangle were moving to the right), (2) in incompatible trials (INCOMP) dots within the triangle or square were moving coherently in a direction opposite to the correct side (e.g., the correct response to a square was to press the left-hand button but the target dots were moving to the right), and (3) during neutral trials (NEU) dots were moving upwards, therefore evoking neither interference nor facilitation. In 25% of all trials the stimulus was either INCOMP or NEU which has been demonstrated as a prerequisite of inducing interference effects (Braver et al., 2001). The stimuli always appeared at the center of the screen, subtending an area of 2.8° of visual angle.

Subjects had to press the left-hand button as fast and correct as possible if coherently moving dots formed a square and the right-hand button if a triangle was presented. The experiment was run in two sessions with a short break in-between runs and consisted of a total number of 500 stimuli. The sequence of trials was presented in a pseudo-randomized order, eliminating two consecutive incompatible trials. Left-hand responses and right-hand responses were counterbalanced.

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