BRIEF REPORT

Effect of the irrelevant location of the response signal on choice reaction time: An electromyographic study in humans

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Abstract
Choice reaction time (RT) is shorter when the stimulus corresponds spatially to the response than when the stimulus does not, even when the stimulus location is irrelevant to the task. We used electromyographic measures to document that this effect is the result of a response conflict. The activity of the prime movers of two alternative responses was recorded during the performance of a visual RT task in which the irrelevant spatial correspondence between the stimuli and the responses was varied. Only the premotor component of RT was affected by the stimulus–response correspondence. Correct trials were distinguished according to whether or not the activation of the prime mover involved in the required response was preceded by an activation of the prime mover involved in the alternative response. Double muscular activation trials were more numerous for noncorresponding than for corresponding stimulus–response associations. Furthermore, these trials yielded longer RTs than the single muscular activation trials.

Descriptors: Simon effect, Spatial compatibility, Response activation, Motor processes

In sensorimotor tasks, when human subjects are required to select their responses according to a spatial criterion, choice reaction time (RT) is shorter when the spatial location of the stimulus corresponds to that of the response than when the location does not. Simon and colleagues have shown that the spatial relationship between the stimulus and the response need not be relevant for affecting the subjects’ performance (see Simon, 1990). For instance, when the subjects have to choose between a left- and a right-hand keypress according to the color of a stimulus light presented either on the left or on the right of fixation, RT is shorter for ipsilateral (congruent) than for contralateral (incongruent) stimulus–response associations (Craft & Simon, 1970). This phenomenon, usually referred to as the “Simon effect” in the literature, has proved to be replicable across sensory modalities (Simon, 1990). The debate following an alternative proposal by Hasbroucq and Guiard (1991) resulted in general agreement that the Simon effect reflects—at least in part—a response conflict. According to recent models, the location of the stimulus automatically activates its spatially corresponding response (de Jong, Liang, & Lauber, 1994; Kornblum, 1994). This automatic activation facilitates the controlled processing of the relevant stimulus attribute (e.g., its color) when the stimulus–response association is congruent and interferes with processing when the stimulus–response association is incongruent.

Studies combining electroencephalographic (EEG) techniques with RT measures have strengthened the motoric interpretation of the Simon effect (de Jong et al., 1994; Valle-Inclán, 1996). It was shown that for congruent associations, the readiness potential (RP) recorded during RT over the motor areas of the hemisphere contralateral to the required response became larger than that recorded over the homologous areas of the ipsilateral hemisphere. This difference in activity started soon after the stimulus onset and lasted until response execution. For incongruent associations, the RP recorded over the motor areas was first larger over the hemisphere ipsilateral to the required response. Later on and until response execution, the hemisphere controlling the required response became more active than the other hemisphere. This finding suggests that for congruent associations, only the correct response is activated. However, for incongruent associations, the activation of the correct response is preceded by an activation of the incorrect response. Note, however, that results from the study of Wascher and Wauschkuhn (1996) suggested that the early activation recorded over the ipsilateral motor cortex may be a contamination of ipsilateral parietal activation, which argues against a purely motor interpretation of the Simon effect (see also Eimer, 1996).
These results resemble those obtained in the context of the flanker compatibility task (Eriksen & Eriksen, 1974) in which the subject typically has to make a left- or a right-hand keypress according to the identity of a letter (e.g., A or H). This target is flanked by noise letters on each side. The flanks are either “compatible” (e.g., AAA) or “incompatible” (e.g., HAH) with the target. Incompatible displays yield longer RTs than compatible displays. The most common interpretation is that the flanks automatically activate the required response when the display is compatible and the nonrequired response when the display is incompatible. Information processing is assumed to be facilitated in the compatible case and interfered with in the incompatible case (Eriksen & Schultz, 1979). Numerous EEG studies support this notion (see, e.g., Gehring, Gratton, Coles, & Donchin, 1992; Gratton, Coles, & Donchin, 1992; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Smid, Mulder, & Mulder, 1990). They suggest that when the display is compatible, only the hemisphere controlling the required response is activated, whereas there is an initial activation of the hemisphere controlling the nonrequired response when the display is incompatible. Like that evidenced for the Simon effect, such a difference in EEG activity is considered to index a response conflict at the central (cortical) level.

Electromyographic (EMG) data recorded in the context of the flanker compatibility task further suggest that the response conflict has peripheral consequences (Eriksen, Coles, Morris, & O’Hara, 1985). Eriksen et al. fractionated the RT into two intervals with respect to the onset of the activation of the prime mover involved in the required response. Both intervals, respectively termed premotor time and motor time, were longer for incompatible than for compatible stimulus displays. The motor time effect indicates that the compatibility between the flanker and the target affects response execution. Another important finding was that the muscle involved in the nonrequired response was often activated during correct trials and more frequently so for incompatible than for compatible displays. Moreover, such double activation trials exhibited longer RTs than other trials. Assuming that muscular activity reflects response activation, these results support the view that the response conflict has peripheral consequences that are in part responsible for the flanker compatibility effect. Smid et al. (1990) refined this analysis by distinguishing trials in which the EMG activation of the prime mover involved in the nonrequired response preceded that of the prime mover involved in the required response from those in which, conversely, the activation of the prime mover involved in the required response preceded that involved in the nonrequired response. Smid et al. demonstrated that only the former type of trials contributed to the flanker compatibility effect.

Because, as demonstrated by the studies cited above, such analyses can lead to important theoretical conclusions, it is surprising that no EMG study of the Simon effect has yet been published. The purpose of the present study was to analyze the activity of the prime movers during the performance of a task comparable to that studied by Craft and Simon (1970) with the aim of providing new empirical evidence for interpreting the Simon effect.

**Method**

**Subjects**

Twelve subjects (6 women) aged between 20 and 35 years ($M = 25$ years) volunteered for the experiment. Two subjects were left-handed. All had normal or corrected-to-normal visual acuity and normal color vision.

**Display and Apparatus**

Seated in a dentist chair, the subject faced a black plastic board on which the stimuli were presented. The distance between this screen and the subject’s eyes was 1 m. A yellow light-emitting diode (LED) fixed at the center of the screen served as fixation. The stimuli were delivered by three bicolor (red/green) LEDs located at the vertices of an equilateral triangle, the center of which was the fixation LED. The upper vertex of the triangle was directly above the fixation and the two lower vertices were arranged along an horizontal line slightly below the fixation. The distance between the bicolor LEDs was 4.6 cm. Two plastic cylinders (3 cm in diameter, 7.5 cm in height) fixed 20 cm apart on a pull-out table served as handgrips. A force sensor was glued at the top of each handgrip. The subject kept the distal phalanx of the left thumb on the left sensor and the distal phalanx of the right thumb on the right sensor. The response was an isometric press of about 1 kg on one of the two sensors depending on the color of the stimulus. When the stimulus was lit, the stimulus–response association was neutral; when one of the lower-lateral LEDs was lit, the association was either congruent or incongruent, depending on whether the required response was on the same side or on the opposite side as the signal.

**Design and Procedure**

A trial started with the illumination of the fixation. One second later, a bicolor LED was illuminated either in red or in green. According to the color of this signal, the subject was to press on either the left or the right force sensor, as quickly as possible. The response extinguished both the fixation and the stimulus LEDs. The next trial started 500 ms after the response criterion was reached. The trials were presented in blocks of 72 in a pseudorandom order such that all stimuli were equiprobable. Between each block, the subject was given a few minutes rest.

The experiment comprised two training sessions (5 blocks of trials each) and an experimental session (10 blocks). The EMG activity was recorded during the experimental session only. The assignment of the left and right force sensors to a color light was balanced across subjects.

**Signal Recordings**

The EMG activity of the *flexor pollicis brevis* was recorded by means of paired surface Ag-AgCl electrodes, 8 mm in diameter, fixed about 10 mm apart on the skin of the Thenar eminence. The EMG activity was amplified (gain = 5,000), filtered (high-frequency cut-off 1 KHz), full-wave rectified and integrated (time constant = 5 ms). This signal was digitized online at a rate of 2 KHz.

The thumb presses were measured as a force signal and digitized online at the same rate as the EMG signal.

**Signal Processing**

For each trial, the stored EMG and force signals were displayed on a computer screen. The onset of changes in activity in EMG and force signals were determined visually and marked with a cursor by using the computer mouse. Although laborious, this method was preferred to an automated method because this method allows a precise detection provided that the EMG is recorded at a high sampling rate with a high antialiasing filter frequency (Van Boxtel, Geraats, Van den Berg-Lenssen, & Brunia, 1993). To overcome subjective influence on the scoring, the experimenter who processed the signals was unaware of the type of associations (congruent, neutral, incongruent) to which the traces corresponded.
Data Analysis

The data recorded during the training sessions were discarded. The chronometric variables analyzed in the present study are illustrated in Figure 1.

RT was measured from the onset of the imperative signal to the onset of change in the force signal corresponding to the required response. RT was next fractionated into premotor time and motor time. The contraction time—defined as the interval between the onset of change in the force signal and the time at which the response threshold (~1 kg) was crossed—was also measured. Changes in the EMG activity of the effector involved in the nonrequired response were detected, counted, and dated when this activity preceded that of the effector involved in the required response. The latency of such incorrect activations—referred to as the “incorrect activation time” below—constituted the fifth chronometric index measured in the present study.

Results

Except for the comparisons between the different types of correct trials, the analyses of variance (ANOVAs) reported in the present section involved type of stimulus–response association (congruent, neutral, incongruent) as a within-subject variable. Proportions cannot be submitted to parametric analyses because their means and variances are related. The arcsine transform has proved to be effective in stabilizing the variances of such data (see Winer, 1970). Thus, the proportions reported in this section were transformed accordingly before being submitted to ANOVAs.

Errors

Errors (incorrect overt responses) occurred in 3.81% of the trials. The error rate was 4.6%, 3.34%, and 3.49% for incongruent, neutral, and congruent associations, respectively. The arcsine transforms of the frequency of errors per condition of congruity was submitted to an ANOVA. The numerical difference between conditions of congruity failed to reach significance level, F(2,22) = 2.52, p = .103. Erroneous trials were excluded from further analyses.

Overall Reaction Time

The overall RT showed a Simon effect, F(2,22) = 52.78, p < .001, ε = 0.8930. Congruent associations (286 ms) lead to shorter RTs than neutral associations (303 ms), F(1,11) = 45.99, p < .001. Symmetrically, neutral associations yielded shorter RTs than incongruent associations (316 ms), F(1,11) = 14.16, p < .004.

Rejected Trials

Owing to tonic activity or artifacts (wire movements), 6.19% of the correct trials were rejected. The rejection rate was 6.45%,
6.21%, and 5.9% for congruent, neutral, and incongruent associations, respectively. The arcsine transforms of the frequency of rejections were submitted to an ANOVA, which revealed no link between trial rejection and congruity, $F(2,22) < 1$.

**Repartition of Correct Nonrejected Trials**
Correct nonrejected trials were distinguished according to whether or not the activation of the prime mover involved in the required response was preceded by an activation of the prime mover involved in the alternative response (see Figure 1). In what follows, trials presenting such a dual activation are termed “incorrect-correct” and the other trials “pure-correct.” Incorrect-correct and pure-correct trials occurred in 11% and 89% of correct nonrejected trials, respectively. One subject did not make any incorrect-correct responses when the association was congruent.

The arcsine transforms of the frequency of incorrect-correct trials were submitted to an ANOVA. Incorrect-correct trials were more numerous for incongruent (16.97%) than for neutral (9.67%) associations, $F(1,11) = 54.58, p < .001$. Symmetrically, these trials were more numerous for neutral than for congruent (6.37%) associations, $F(1,11) = 13.99; p < .004$.

**Pure-Correct Trials**
The results are summarized in Figure 2. The Simon effect was present on RT, $F(2,22) = 23.23, p < .001, \epsilon = 0.6299$. The RT was shorter for congruent stimulus–response associations (279 ms) than for neutral associations (296 ms), $F(1,11) = 40.59, p < .001$.

![Figure 2](image-url)

**Figure 2.** Reaction time (circles), premotor time (squares), motor time (triangles), contraction time (diamonds), and incorrect activation time (stars) as a function of stimulus–response congruence (C, N, and I stand for congruent, neutral, and incongruent associations, respectively) for pure-correct trials (open symbols) and incorrect-correct trials (filled symbols). Bars indicate the standard errors.

...and for neutral associations than for incongruent associations (306 ms), $F(1,11) = 7.011, p < .03$.

The premotor time exhibited the Simon effect, $F(2,22) = 57.28, p < .001, \epsilon = 0.7752$. Congruent associations (244 ms) yielded shorter premotor times than neutral associations (261 ms), $F(1,11) = 45.61, p < .001$; neutral associations lead to shorter premotor time than incongruent associations (271 ms), $F(1,11) = 8.76, p < .02$.

Congruent, neutral, and incongruent associations yielded similar motor times (35 ms).

Contraction time was unaffected by congruity, $F(2,22) = 1.18, p = .326$. The contraction time values were 91, 89, and 94 ms for congruent, neutral, and incongruent associations, respectively.

**Incorrect-Correct Trials**
The analyses were performed on 11 subjects only (see above). Figure 2 illustrates the results. There was a marginally significant tendency for an inverse Simon effect on RT, $F(2,20) = 2.74, p = .10, \epsilon = 0.7245$. Congruent associations (385 ms) tended to yield longer RTs than neutral associations (369 ms), $F(1,10) = 3.61, p = .087$. However, there was no difference in RT between neutral and incongruent associations (371 ms), $F(1,10) < 1$.

There was no effect of congruity on the premotor time, $F(2,20) = 1.94, p = .1681$. However, like the corresponding RTs, the premotor times of congruent associations (347 ms) tended to be longer than those of neutral associations (334 ms), $F(1,10) = 3.65, p = .0825$. There was no difference in premotor time for neutral and incongruent associations (333 ms), $F(1,10) < 1$.

The congruity of the association exerted no detectable effect on motor time, $F(2,20) < 1$. There was no difference on motor time, neither between congruent (38 ms) and neutral associations (35 ms), $F(1,10) < 1$, nor between neutral and incongruent associations (38 ms), $F(1,10) = 2.21$.

Contraction time was unaffected by congruity, $F(2,22) < 1$. The contraction time values were 93, 88, and 87 ms for congruent, neutral, and incongruent associations, respectively.

In contrast, incorrect activation time was affected by congruity, $F(2,20) = 7.86, p < .02, \epsilon = 0.7449$. There was no difference on this variable between congruent (239 ms) and neutral associations (226 ms). However, neutral and congruent associations (232 ms) yielded longer incorrect activation time than incongruent associations (208 ms), $F(1,10) = 12.183, p < .006$.

**Comparison Between Pure-Correct and Incorrect-Correct Trials**
The differences in RT, premotor time, motor time, and contraction time between these two types of trials (Figure 2) were estimated by ANOVAs. In these analyses, trial type (pure-correct vs. incorrect-correct) was treated as a within-subject variable.

Reaction time was 81 ms longer for incorrect-correct than for pure-correct trials, $F(1,10) = 72.37, p < .001$. Likewise, premotor time was 79 ms longer for incorrect-correct than pure-correct trials, $F(1,10) = 106.07, p < .001$. In contrast, there was no other detectable difference between incorrect-correct and pure-correct trials, neither on motor time, $F(1,10) = 1.8, p = .209$, nor on contraction time, $F(1,10) = 1.08, p = .323$.

**Discussion**
The size of the Simon effect obtained on the overall RT of the present study compares with that typically obtained with visual displays (Craft & Simon, 1970). This congruity effect was evident on the pre-
motor time, which can be considered as an index of central processing but not on the motor and contraction times, which reflect peripheral motor processes. One may thus tentatively conclude that the Simon effect essentially reflects central mechanisms.

In 11% of the correct trials, a detectable activation of the prime mover involved in the nonrequired response preceded that of the activation of the prime mover involved in the required response. The occurrence of incorrect-correct trials depended on the congruity of the stimulus–response association: They were more numerous for incongruent than for neutral associations and more numerous for neutral associations than for congruent associations. Furthermore, these double activation trials were associated to longer RTs than the other correct trials. This finding indicates that the presence of incorrect-correct trials contributes to the Simon effect evidenced on the overall RT. The present results complement those obtained with EEG techniques (de Jong et al., 1994; Valle-Inclán, 1996) and are compatible with the notion, recently challenged by Valle-Inclán, Craft, J. L., & Simon, J. R. (1990), that the Simon effect essentially reflects central mechanisms. One may thus tentatively conclude that motor time, which can be considered as an index of central process-

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also differ from those evidenced with the flanker compatibility task. First, in our study, there was no evidence for an effect of congruity on motor time and contraction time, whereas Eriksen and collaborators as well as Smid et al. reported an effect of flanker compatibility on a dependent variable summing these two intervals. Second, we found no evidence for a Simon effect on the incorrect-correct trials. This finding contrasts with those of Smid et al. (1990), who reported a flanker compatibility effect of 53 ms on the RT of the same trial type. Third, in the present study, there was an inversion of the Simon effect on the incorrect activation time, whereas in the Eriksen task, the incorrect activation time is shorter for compatible than for compatible flankers (e.g., Rösler & Finger, 1993).

Admittedly, the two former differences between the flanker compatibility and the Simon effects are tied to null-results reported here and could therefore reflect a lack of precision of our study. However, the latter difference can be accounted for in terms of Kornblum’s (1994) taxonomy. Kornblum has proposed a taxonomy of tasks based on the notion of dimensional overlap. Dimensional overlap is conceived as a continuous variable that characterizes the degree to which sets of items are conceptually similar (i.e., share the same mental representations). The Simon effect is typical of “type 3” ensembles in which the overlap occurs between the response set and an irrelevant stimulus dimension. In contrast, the flanker compatibility effect occurs when “type 4” ensembles have to be processed. In type 4 ensembles, the overlap is between a relevant and an irrelevant stimulus dimension. The effect of congruity observed in the present study on the incorrect activation time was clearly caused by the presence of dimensional overlap between the stimulus and response sets. By definition, such an effect cannot be obtained in the flanker compatibility task in which the dimensional overlap is between two stimulus dimensions.

REFERENCES


(Received September 9, 1998; Accepted December 9, 1998)