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Stimulus-response dimensional overlap elicits a decreasing Simon effect along the vertical dimension

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Abstract

In Simon task, the response is faster when stimulus and response locations are spatially correspondent than when they are on opposite sides (Simon effect – SE). The SE was found with both horizontal and vertical stimulus-response arrangements. The horizontal SE decreases as reaction times increase. In contrast, the vertical SE does not decay over time. In this work, we investigate the vertical SE when both stimuli and responses are located along the vertical dimension. Results showed a decreasing SE occurring along the vertical dimension suggesting that similar underlying mechanisms may be involved both for the horizontal and vertical Simon effects.

Keywords: dimensional overlap; Simon effect; vertical dimension.

Resumo

A sobreposição dimensional entre o estímulo e a resposta na dimensão vertical provoca um decaimento do efeito Simon. Na tarefa de Simon, a resposta é mais rápida quando os locais do estímulo e da resposta são espacialmente correspondentes do que quando estão em lados opostos (efeito Simon - ES). O ES foi observado ao longo das dimensões horizontal e vertical. O ES horizontal diminui à medida que aumenta o tempo de reação, o que não ocorre com o ES vertical. Neste trabalho, investigamos o ES vertical com estímulos e respostas localizados ambos ao longo da dimensão vertical. Os resultados mostraram um ES decrescente na dimensão vertical sugerindo que mecanismos semelhantes estão envolvidos nos efeitos Simon horizontal e vertical.

Palavras-chave: sobreposição dimensional; efeito Simon; dimensão vertical.

Resumen

Superposición dimensional induce la disminución del efecto Simon en la dimensión vertical. En la tarea de Simón, la respuesta es más rápida cuando el estímulo y la respuesta son espacialmente correspondientes que cuando están en lados opuestos (efecto Simon - ES). La ES se observó en las dimensiones horizontal y vertical. El ES horizontal disminuye con el aumento del tiempo de reacción, lo que no ocurre con ES vertical. En este trabajo, se investigó el ES vertical con estímulos y respuestas situadas en la dimensión vertical. Los resultados mostraron una disminución del ES en la dimensión vertical lo que sugiere que mecanismos similares están implicados en los efectos Simon horizontal y vertical.

Palabras clave: superposición dimensional; efecto Simon; dimensión vertical.

In choice manual reaction time (MRT) paradigms, spatial location is an intrinsic property of the stimulus and cannot be ignored (Tsal & Lavie, 1993), affecting performance even when it is irrelevant to the task, as shown by the Simon effect (Simon, 1990). In the Simon task participants are instructed to respond according to a stimulus attribute (e.g. shape or color), irrespective of its spatial location. Despite this instruction, the MRT is faster and more accurate when stimulus and response spatially correspond.

Several models have been proposed to explain the Simon effect, and the most accepted one invokes two distinct pathways (e.g., De Jong, Liang, & Lauber, 1994; Iani, Milanese, & Rubichi, 2014; Marini, Iani, Nicoletti, & Rubichi, 2011; Ridderinkhof, 2002; Rubichi, Nicoletti, Umiltà, & Zorzi, 2000). According to this model, the stimulus onset activates the corresponding response through an unconditional route, irrespective of the instruction of the stimulus identification. At the same time, through a conditional route, the identification of stimulus activates the correct response in a controlled way. If these two routes activate the same response, the correct response is rapidly executed. If not, the incorrect response must be aborted before the correct response can be executed increasing the response latency.

The time-course of these processes has been investigated through analysis of the reaction time (RT) distributions (De Jong et al., 1994; Ellinghaus, Karlbauer, Bausenhart, & Ulrich, 2017; Proctor, Miles, & Baroni, 2011; Ridderinkhof, 2002). This technique has revealed that the direct (unconditional) response activation occurs soon after the stimulus onset and then dissipates over time leading to a decrease of the Simon effect as RT increases (e.g., Ellinghaus et al., 2017; Proctor, Yamaguchi, Zhang, & Vu, 2009; Rubichi & Pellicano, 2004). However, there are other instances where the Simon effect increases or remain stable such as in the standard left–right auditory Simon task, when responses are made with crossed hands and, when the stimulus and response locations are arrayed vertically rather than horizontally (Vallesi, Mapelli, Schiff, Amodio, & Umiltà, 2005; Wascher, Schatz, Kuder, & Verleger, 2001; Wühr, 2006, but see Xiong & Proctor, 2016).

In short, the Simon effect has been observed along the three spatial dimensions: horizontal, vertical and sagittal (see review in Proctor et al., 2011; Rigon, Massaccesi, & Umiltà, 2011). However, as pointed out by Proctor et al. (2011), the pattern of reaction time distribution may vary according to the spatial dimensions. For instance, Vallesi et al. (2005) compared a horizontal and a vertical Simon task by means of a RT time-course analysis of the Simon effect. The distributional analysis revealed a substantially different time-course of the two effects. In the horizontal task, the Simon effect decreased as RT increased, whereas in the vertical task the Simon effect increased or did not change as a function of RT latency. This difference between decays of the horizontal and vertical Simon effects is widely accepted and supports the proposal that different mechanisms underlie them (Vallesiet al., 2005; Wascher et al., 2001; Wühr, 2006, but see Xiong & Proctor, 2016).

Another important difference between horizontal and vertical Simon effects refers to the transfer-of-learning from a short incompatible practice to the Simon effect. Tagliabue and co-workers (2000) showed that 72 incompatible trials in a previous spatial compatibility task modulate the Simon effect along the horizontal dimension. Similar transfer of learning after a short practice has not been found along the vertical dimension or across vertical and horizontal dimensions. For example, Vu (2007) examined the influence of prior practice with incompatible spatial mappings on the Simon effect as a function of the dimension (vertical or horizontal) along which the stimuli and responses are located, as well as the number of trials in the previous incompatible practice. Her study showed that after a short practice with 72 incompatible trials, the Simon effect was eliminated only when the spatial dimension was horizontal for both practice and Simon task. On the other hand, the Simon effect was eliminated for all combinations of dimensions between practice and Simon task after 600 incompatible trials. However, the recent work of Conde et al. (2015) showed that the modulatory effect after a small number of incompatible trials may be observed by changing the spatial arrangement of the vertical response keys in order to obtain a stronger dimensional overlap between the spatial codes of stimuli and responses. In their work, they found a transfer-of -learning after a small number of incompatible trials along the vertical dimension and across vertical and horizontal dimensions.

We wondered whether the difference between horizontal and vertical Simon effects in relation to the Simon effect decay, as well as to the transfer-of-learning after a short incompatible practice occurs because horizontal keyboards are used for recording the responses both in horizontal and vertical Simon tasks. By using this arrangement, there is a perfect dimensional overlap between stimulus

and response locations along the horizontal dimension. In contrast, in the vertical Simon task, while the stimuli occurred along the vertical dimension, the keys are located nearer and farther from the participant (i.e., along the depth dimension such as the "2" and "8" keys) and it is assumed that depth dimension represents also the vertical dimension (Buetti & Kerzel, 2008; Töbel, Hübner & Stürmer, 2014; Vallesi et al., 2005; Vallesi & Umiltá, 2009; Vu, Proctor, & Pick, 2000; Wuhr & Biebl, 2011;). Actually, this paradigm implies a need to translate the vertical stimulus dimension to the response key (depth) dimension.

Thus, to the best of our knowledge, until now, besides De Jong et al. (1994) Experiment 4, in which they used two vertical stimuli and a computer keyboard "rotated 90° counterclockwise resting on the subject's lap at approximately 45° vertical angle" and found a decreasing Simon effect, there is no other work studying the temporal distribution of the Simon effect exclusively along the vertical dimension. The objective of this work was to replicate De Jong et al. (1994) experiment 4 using a new setup to test the hypothesis that there is always an automatic and transient facilitation of the corresponding response, eliciting a decaying Simon effect function when stimuli and responses are both located along the same dimension. If this is true, there will be also a decreasing Simon effect along the vertical dimension when there is a dimensional overlap between stimulus and response keys positions. Moreover, since Tagliabue et al. (2000) showed that a previous incompatible practice reduces the horizontal Simon effect without changing the Simon effect time course, we expect to find a similar result for the vertical Simon effect decay. For testing the hypothesis that there is no main difference between Horizontal and Vertical Simon decay, we investigated the vertical Simon effect decay in three groups of participants: in one, there was no previous compatibility task and in second and third groups, a compatible and an incompatible task, respectively, were applied before the vertical Simon task. We found similar decreasing Simon effects in the three groups, supporting our proposal that similar underlying mechanisms may be involved in horizontal and vertical Simon effects.

Methods

Participants

The experiment involved 24 students (13 male and 11 female) from the Universidade Federal Fluminense (Rio de Janeiro, Brazil), aged 15-29 years (M = 21.87, SD = 3.90). All participants were right-handed (Oldfield 1971), had normal or corrected-to-normal vision and were naive about the purposes of the experiment. Written informed consent form was obtained from all subjects, and the study was approved by the Institutional Ethics Committee of the Universidade Federal Fluminense (# 185/2005). All procedures performed in the study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments.

Apparatus and Stimuli

The experiment was performed in a dimly lit and soundproof chamber. Participants sat in front of a monitor at a viewing distance of approximately 57 cm. The head of each participant was positioned in a forehead-and-chin rest. A personal computer (IBM-PC 486) and a Samsung SyncMaster 20 GLs monitor were used both for stimulus presentation and for response recording. The Micro Experimental Laboratory software (MEL, version 2.0) was used to determine event sequences and to measure response latency. For the spatial compatibility task (practice session), the imperative stimulus was a solid black circle .5° in diameter, randomly presented at 6.5° above or below the fixation point (FP). In the Simon task, there were two imperative stimuli: the outline of a circle or a square that were randomly presented 6.5° above or below the FP. The square was 1° × 1° in size and the circle 1° in diameter. The screen was light gray and the stimuli were black. The FP was a .7° × .7° cross. MRT was measured from stimulus onset to the execution of the response. The stimulus remained present for 1000 ms or until a response was given. The trial terminated if the subject did not respond within 1000 ms. The inter-trial interval was of 2000 ms. In both tasks, responses were given by using switches placed vertically in front of the body midline with a distance of 9 cm between the two keys. The hands and the upper arm were rested on the table or on a support located at 7.5 cm above the table surface allowing a comfortable arrangement for the execution of the responses. The distance between the keys and the monitor was 30 cm. The table height was 72 cm, and the eyes and the fixation point were centered 49 cm above the table surface (Figure 1). The assignment of left and right hands to the top and bottom response keys was counterbalanced across subjects. Responses faster than 100 ms or slower than 1000 ms were considered errors and were repeated at the end of the session.

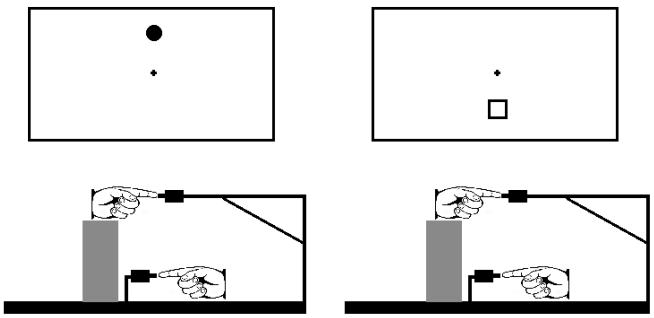

Figure 1. Stimulus and response key locations along the vertical axis in the spatial compatibility task (left) and in the Simon task (right).

Procedure

There were three groups of participants, each group with eight volunteers. In the first group, there was no practice session. Participants only performed a Simon task. They had to respond (with the top or the bottom key) when a stimulus (circle or square) appeared on the screen. In this task, only the geometric form was relevant for response selection. The Simon task consisted of two blocks of 80 correct trials, preceded by 20 training trials (not analyzed). In the second and third group, there was a practice session with a Spatial Compatibility task. The second group was instructed to respond with a spatially compatible mapping, by pressing the top key to the top stimulus and the bottom key to the bottom stimulus. The third group had to respond with a spatially incompatible mapping (by pressing the bottom key to the top stimulus and the top key to the bottom stimulus). The practice session consisted of 80 correct trials. The vertical Simon task was conducted after the Spatial Compatibility task, with a delay of 5 min between the two tasks. As for the first group of participants, the Simon task consisted of two blocks of 80 correct trials, preceded by 20 training trials.

Analyses

Vicentization Procedure. In the Simon task, following the Vincentization procedure introduced by Ratcliff (1979), we divided the MRT distributions for each participant and for the two Correspondence conditions into five bins (quintiles) such that each bin contained the same proportion (one fifth) of trials. Means were computed for each bin and used in an ANOVA with Previous practice (no practice, compatible practice or incompatible practice) as a between-subjects factor and Correspondence (corresponding and non-corresponding conditions) and bin or quintile (1st bin, 2nd bin, 3rd bin, 4th bin and 5th bin) as within-subjects factors.

A corresponding trial was the condition in which the stimulus appeared on the same side of the response key. For example, when the stimulus appeared in the top (bottom) visual hemifield and the participant responded by pressing the top (bottom) key. A non-corresponding trial was the condition in which the stimulus appeared in the opposite side of the response key, for example, when the stimulus appeared in the bottom (top) visual hemifield and the participant responded by pressing the top (bottom) key. Planned comparisons were also conducted to test study hypotheses. Statistical significance was set at .05 and partial eta-squared (η^2) was calculated as an estimate of effect size. The Shapiro-Wilk test indicated that data followed a normal distribution. These analyses were performed using the software *Statistica*, version 8.0.

Results

Errors

Overall errors amounted to 5.6 %. There was a significant effect for Correspondence ($F(1,21) = 7.39$; $p = .013$, $\eta^2 = .24$). There were 4.1 % of errors for the corresponding condition and 7.1 % for the non-corresponding condition. No other factor or interaction was significant.

Reaction Times

There were significant main effects of Correspondence ($F(1,21)= 12.99$, $p < .001$; $\eta^2= .70$) and Bin ($F(4,84)= 963.01$; $p < .000$; $\eta^2= .99$) on MRT. MRT in the corresponding condition (497 ms) was 18 ms faster than MRT in the non-corresponding condition (515 ms) and, as expected, MRT increases for successive Bins (386, 449, 492, 547 and 658 ms, respectively).

There were significant interactions between Previous practice and Correspondence ($F(2,21)= 4.51$; $p < .023$; $\eta^2= .24$), between Correspondence and Bin ($F(4,84)= 6.982$, $p < 0.001$; $\eta^2= .80$) and between Previous practice and Bin ($F(8,84)= 2.55$; $p < .015$; $\eta^2= .19$). The three-way interaction of Practice, Correspondence and Bin was not significant ($F(8,84)= 0.671$, $p = .715$; $\eta^2= .054$), showing that there was no statistically significant influence of Previous practice on the Simon effect decay across bins, such as it had been found for the horizontal dimension by Tagliabue et al. (2000).

For the interaction between Previous practice and Correspondence, planned comparisons showed

typical Simon effects for the No practice group and for the Compatible practice group. However, there was no significant Simon effect for the Incompatible practice group. Specifically, for the No practice group, the difference between corresponding (469 ms) and non-corresponding (497 ms) conditions elicited a regular Simon effect of 28 ms ($F(1,21)= 10.30$; $p < .001$; $\eta^2= .32$). Similarly for the Compatible practice group, the Corresponding (494 ms) condition was 29 ms faster than the non-corresponding (523 ms) condition ($F(1,21)= 11.58$; $p < .002$; $\eta^2= .35$). In contrast, for the Incompatible practice group were not found significant differences between corresponding (530 ms) and non-corresponding (526 ms) conditions ($F(1,21)= .13$; $p = .715$; $\eta^2= .006$, see figure 2).

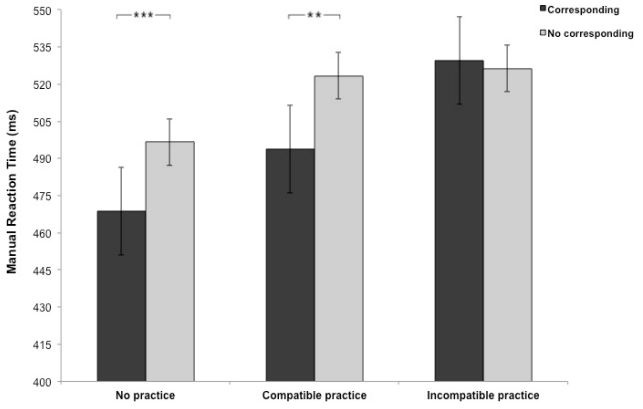

Figure 2. MRT for Corresponding and no corresponding conditions in No-practice, Compatible and Incompatible practice groups. Bars represent the standard error. *p< .05; **p< .005; ***p< .001.

For Correspondence-Bin interaction, planned comparisons showed MRT differences between corresponding and non-corresponding conditions in the 1st bin (27 ms, $F(1,21)= 33,51$; $p < .000$; $\eta^2= .61$) , 2nd bin (28 ms, $F(1,21)= 39.85$; $p < .000$; $\eta^2= .65$), 3rd bin (24 ms, $F(1,21)= 21,66$; $p < .000$; $\eta^2= .50$) and 4th bin (14 ms, $F(1,21)= 4.48$; $p = .046$; $\eta^2= .17$). There was no difference in the 5th bin (- 2 ms, $F(1,21)= .02$; $p = .871$; $\eta^2= .001$) (see figure 3).

These results showed that the amplitude of the Simon effect decreased for the shortest to the longest bin (Figure 4 – thicker line). Although the three-way interaction of Practice, Correspondence and Bin was not significant ($F(8,84)= 0.671$, $p = .715$; $\eta^2= .054$), we plotted the Simon decay for each group for showing that the incompatible practice reduced the Simon effect in all bins without changing the Simon effect decay.

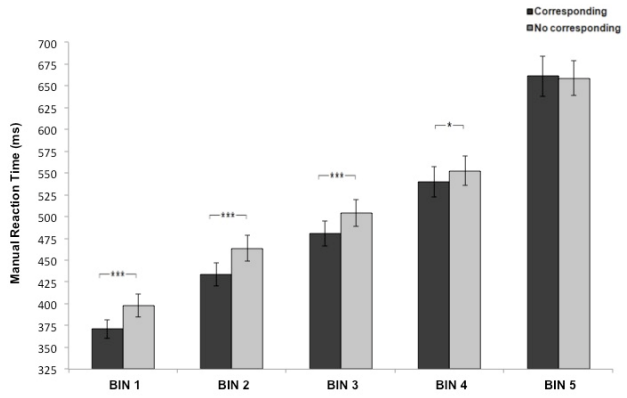

Figure 3. Manual reaction time in corresponding and no corresponding conditions for each Bin. Bars represent the standard error. *p< .05; **p< .005; ***p< .001.

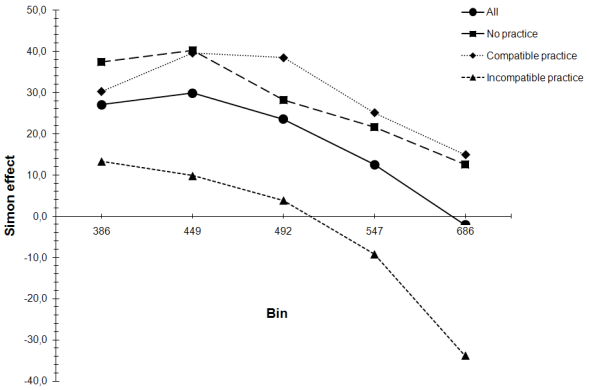

Figure 4. Simon effect amplitude for corresponding and non-corresponding conditions and bin. It can be observed that the Simon effect amplitude decreases as MRT becomes longer.

Discussion

This is the first work aimed to study the temporal distribution of the Simon effect with both stimuli and response keys located along the vertical dimension, besides De Jong et al. (1994 - Experiment 4). Its objective was to investigate whether strong similarities between the stimulus and response sets may influence the MRT distributional pattern described previously for the vertical Simon effect. Here, the stimulus was presented along the vertical dimension in the frontal plane and the participants performed the Simon task with vertical switches placed centrally, one above the other. The distributional analysis (Ratcliff, 1979; Ridderinkhof, 2002) was used to reveal the temporal dynamics of the vertical Simon effect. The results showed that the Simon effect decreases as a function of MRT latency, in contrast to previous studies on the Vertical Simon effect (Buetti & Kerzel, 2008; Töbel et al., 2014; Vallesi et al., 2005; Vallesi & Umiltá, 2009).

We believe that the reason for the discrepancy between the decaying Simon effect found in the present study and the constant or increasing Simon effect observed in the other works is due to the spatial arrangement of the response keys. In the other studies, the numeric pad, computer keypad or responses box were placed flat on the table and, for instance, the "8" and "2" keys of a number keypad were considered as equivalent to the top and bottom keys, respectively. Thus, in those experiments, the vertical response key dimension corresponded to the depth (far-near) dimension and it was necessary to translate the vertical stimulus dimension code to the response key (depth) dimension code (Proctor, Vu, & Nicoletti, 2003). This cognitive step may activate a controlled process at expenses of the automatic response activation. This is in agreement with Wascher et al. (2001) which attributed the differing time courses of the various Simon effects to the distinction between visuomotor activation and cognitive translation of spatial stimulus codes.

Töbel et al. (2014) proposed that RT distribution in horizontal and vertical Simon differs quantitatively, but not qualitatively, even when a horizontal keyboard is used to record the responses. They found that, in their Experiment 1, the Simon effect decreased in the horizontal Simon task but slightly increase in the vertical Simon task. Similar findings for the vertical Simon task were observed in Experiment 2. Thus, there is no evidence of a decreasing Simon effect along the vertical dimension in these two experiments in which the response keys are arranged along the sagittal dimension. However, Töbel et al.'s (2014) findings of a decreasing Simon effect function in the error rate data across the RT distribution and similar sequential effect patterns similar to those for a horizontal Simon task is in agreement with the conclusions that their configuration could involve an extra translation process. When that translation process is removed, as in the present study, the activation is sufficiently strong to reveal the decay in the vertical Simon effect.

Considering that the Simon effect depends on both stimulus and response properties (Proctor & Vu, 2006), it is not surprising that a stronger facilitation is found when the dimensional overlap is enhanced by arranging both the stimuli and the response keys vertically rather than horizontally. Conde et al.'s (2015) results support these findings by showing that the transfer of learning along the vertical and across vertical and horizontal dimensions can be obtained with a smaller number of incompatible trials than was reported earlier by Vu (2007), by just changing the spatial arrangement of the vertical response keys.

The similarity between the time-course of the vertical and horizontal Simon effects suggests that they are coded in Cartesian coordinates. This hypothesis is supported by the absence of horizontal-vertical differences in the automatic or voluntary orientation of attention and in the programming and execution of saccadic eye movements (see review in Gawryszewski, Carreiro, & Magalhães, 2005). All these considerations are relevant to the proposal that the premotor theory of attention can explain the Simon effect (Gawryszewski, Riggio, Rizzolatti, & Umiltà, 1987; Nicoletti & Umiltà, 1989, 1994; Rigon et al. 2011; Rizzolatti, Riggio, & Sheliga, 1994; Umiltà, Riggio, Dascola, & Rizzolatti, 1991; Van der Lubbe & Abrahamse, 2011; Van der Lubbe, Abrahamse, & De Kleine, 2012).

In sum, our findings demonstrate that a Vertical Simon task in which both stimuli and response keys are arranged along the vertical dimension produces a decreasing Simon effect with a time course similar to that observed for a horizontal Simon task. These results are in accordance with Conde et al.'s (2015) findings which showed that the spatial arrangement between response key and stimulus locations may be critical to establish the short-term memory links that enable the transfer of learning between brief incompatible practices and the Simon effects along horizontal, vertical and across vertical and horizontal dimensions. Since equivalent results are obtained when the vertical and the horizontal dimensions are properly aligned, we can conclude that similar underlying mechanisms may be present in both horizontal and vertical Simon tasks.

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