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RESEARCH ARTICLE

Vertically arrayed stimuli and responses: transfer of incompatible spatial mapping to Simon task occurs regardless of response-device orientation

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Abstract Conde et al. (Exp Brain Res 233:3313–3321, 2015) found that the Simon effect for vertically arrayed stimuli and responses was reduced after 100 prior practice trials with an incompatible mapping of the stimulus locations and responses. This finding was contrary to Vu's (Mem Cognit 35:1463–1471, 2007) finding of no transfer effect with 72 trials of prior practice. Conde et al. proposed that the different results were due to their responses being coded as top and bottom in the frontal plane, whereas Vu's were coded as far and near in the transverse plane. We conducted four experiments to test this possibility in which participants responded with keypresses using their thumbs on a numeric keypad held vertically (upright in the frontal plane) or horizontally (flat in the transverse plane). Experiment 1 showed that, without any prior practice, a similar sized Simon effect was obtained when the response device was oriented in the transverse plane as when it was oriented in the frontal plane. In Experiments 2 and 3 participants performed with the same device orientation in the incompatible practice and Simon transfer tasks, with orientation manipulated between-subjects in the former and within-subjects in the latter. The Simon effect was reduced in both cases, with no significant difference in transfer effect for transverse and frontal planes. In Experiment 4, the device orientation differed between the incompatible practice and Simon transfer tasks, and the Simon effect was reduced similarly across both response-device orientations. Thus, the differences between Conde et al.'s and Vu's findings cannot be attributed to the response-device orientation. Our results are consistent with the view that people code response locations in the transverse plane as top and bottom, rather than far and near, in agreement with the terminology of "top row" and "bottom row" for computer keyboards.

Keywords Incompatible practice · Stimulus-response compatibility · Transfer effect · Vertical simon effect

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Introduction

In a two-choice reaction task, the spatial congruence between stimulus and response locations has an influence on task performance. People respond faster when stimuli are mapped to responses on the same side (left → left or right → right) rather than different sides (left → right or right → left). This phenomenon is called the spatial stimulus–response compatibility (SRC) effect (Fitts and Deininger 1954; for a review see Proctor and Vu 2006). The SRC effect also occurs when the stimuli and response key locations are arrayed vertically in top and bottom locations (Vu et al. 2005; Vu and Proctor 2001). Moreover, when the stimulus locations are task-irrelevant and a non-spatial dimension such as color is relevant, people still respond faster when stimulus and response locations are congruent than they are incongruent, a phenomenon called the Simon effect (Simon 1990; for a review see Lu and Proctor 1995).

The Simon effect is typically attributed to activation of the corresponding response produced by long-term associations that have been established through habit or training (Tagliabue et al. 2000). These associations are "primed" as part of the task requirement to discriminate response locations along the same dimension, which allows the stimulus onset to produce conditionally automatic activation of the corresponding response (Ansorge and Wühr 2004; Yamaguchi and Proctor 2012). The tendency to make the corresponding response can be reduced or even eliminated, though, by prior practice with an incompatible mapping of stimulus locations to responses (e.g., Iani et al. 2009).

This transfer effect has been found in several studies, beginning with Proctor and Lu (1999). They had participants practice 600 trials for each of 3 days with a spatially incompatible mapping before performing a Simon task (for which letter identity was the relevant dimension) on the fourth day. In this case, the Simon effect reversed to significantly favor the noncorresponding response. Tagliabue et al. (2000) found that 72 practice trials (plus at least 10 warm-up trials) with a spatially incompatible mapping was sufficient to eliminate the Simon effect, and this reduction was still evident with a 1-week retention interval between practice and the Simon task (see Vu et al. 2005, for similar results).

The transfer effects of the previous two studies were based on tasks for which the stimuli and responses varied along the horizontal dimension (i.e., stimuli were in left and right locations on a frontal screen and responses were left and right keypresses on a keyboard placed on a table). Vu (2007) investigated the transfer effect for situations in which the stimuli and responses varied along the vertical dimension (i.e., in top and bottom locations). Stimuli were displayed in the frontal plane on a computer monitor, whereas responses were made on two vertically arrayed keys located on the numeric keypad of a computer keyboard. In her research, 600 spatially incompatible practice trials reduced the vertical Simon effect (for color discriminations) as well as the horizontal Simon effect. However, with 72 spatially incompatible practice trials, the Simon effect was reduced when both practice and test were conducted on the horizontal dimension, as in Tagliabue et al.'s (2000) study, but not when practice and transfer were on the vertical dimension.

Conde et al. (2015) followed up Vu's (2007) study using a response apparatus that allowed the two responses to vary in top and bottom locations in the frontal plane, matching the display in which the stimulus locations were oriented. In contrast to Vu's results, the Simon effect on the vertical dimension (for circle/square discriminations) was reduced to a nonsignificant 3 ms after 100 spatially incompatible practice trials on the same dimension. Conde et al. hypothesized that the divergence of the results for the two studies could be explained as follows:

> The reason for the discrepancy between her experiment and ours is probably due to the spatial arrangement of the response keys. In her work, the numeric pad was placed flat on the table and the vertical response keys dimension correspond to the depth (far–near) dimension. Considering her experimental setup, except for the horizontal dimension, it is necessary to translate the stimulus (vertical or horizontal) dimension to the response key (depth) dimension. (p. 3320)

In other words, Conde et al. proposed that keys aligned vertically along the transverse plane are coded as near and far, instead of top and bottom, when responding to stimuli presented in vertical locations of a frontal display.

The aim of the present experiments was to evaluate Conde et al.'s (2015) hypothesis about the impact of the orientation of the response device on the transfer effect. We manipulated the plane of responding by having participants hold a numeric keypad in a vertical (upright in the frontal plane) or horizontal (flat in the transverse plane) position, and make the keypresses with their thumbs. The stimuli and the other parameters were similar to those of Conde et al.'s (2015) study. Experiment 1 was designed to establish baseline Simon effects for responses made with the keypad in each orientation. Thus, participants performed only a standard Simon task, with the goal being to establish whether the Simon effects differ in size for the two orientations of the response device. Experiments 2, 3, and 4 employed the practice-transfer paradigm, where participants performed with an incompatible vertical spatial mapping for 100 trials in the practice set and the Simon task in the transfer set. In Experiments 2 and 3, the plane in which the response device was oriented was the same for both the practice spatial task and the Simon transfer task. The difference between Experiments 2 and 3 was whether the device orientation (frontal or transverse plane) was varied between or within subjects. In Experiment 4, we employed conditions in which the plane for the practice set (frontal or transverse) differed from that for the transfer set. Because the display was arrayed vertically in the frontal plane in all cases, Conde et al.'s translation explanation predicts that the Simon effect and the influence on it of prior practice with an incompatible spatial mapping should be larger when the responses are oriented vertically in the frontal plane rather than in the transverse plane.

Experiment 1

Participants performed a standard Simon task, where responses were based on the stimulus shape, as in Conde et al.'s (2015) study. The stimuli were displayed on a computer monitor that was oriented vertically in the frontal plane, and responses were made on a keypad that was oriented vertically in the frontal plane or horizontally in the transverse plane. This experiment allowed us to determine whether similar sized Simon effects would be observed for each response orientation. Conde et al.'s proposal is that responses in the transverse plane are coded with reference to near and far distance and that a translation is required from the reference frame of the vertical stimulus locations to that of the responses. Thus, this translation should result in a smaller Simon effect when the response device is oriented in the transverse plane compared to the frontal plane. However, if the responses are coded as vertical locations regardless of the response orientation, no such translation should be required and, on the basis of dimensional overlap, a similar sized Simon effect should be obtained for the two device orientations.

Methods

The current and subsequent experiments were conducted in accord with a protocol approved by the Purdue University Institutional Review Board, and all participants signed an approved informed consent form at the beginning of the study session.

Participants

24 undergraduate students (12 male; 18 right-handed and 6 left-handed) enrolled in Introductory Psychology courses at Purdue University took part for credits toward a course requirement. Two additional participants were excluded for exceeding an error rate of 10%. All participants had normal or corrected-to-normal vision and were naïve to the experiment's purpose.

Stimuli and apparatus

The experiment was run by a Dell Optiplex 745 personal computer with a Dell 19-inch LCD color monitor. Stimulus presentation, response recording, and feedback were controlled by E-prime 2.0 software. Responses were made with the thumbs on the "2" and "8" keys, the lower and upper positions, of a vertical row on a Logitech Cordless Number Pad, which was held using both of the participant's hands.

The stimuli were unfilled images of a circle and a square, depicted by black contours on a white background. The square was presented in a size of $1° \times 1°$ and the circle with a diameter of 1°. The square or the circle was presented above or below a fixation cross at a distance of 6.5° from center to center. Participants sat in front of the monitor at a distance of approximately 57 cm.

Procedure

After signing consent forms, participants performed the experiment in a dimly lit, quiet room. Each participant sat directly in front of the computer monitor and was instructed to hold the number pad with both hands in the specified orientation during the entire experiment. Each participant performed two sets of 100 trials of the Simon task (the first 20 of which were regarded as practice), with different response-device orientations in the two sets. For the first set, half of the participants were told to hold the number pad vertically (in the frontal plane) with their thumbs on keys "2" and "8" keys (the upper and lower number keys in the center column of the 3×3 number array), whereas the other half were told to hold the keypad horizontally (in the transverse plane) with thumbs on the same keys. All participants switched to the alternative response-device orientation for the second set of trials. Participants held the keypad with their preferred, dominant hand providing primary support at the bottom (the thumb placed on the "2" key) and the other hand providing secondary support at the top (the thumb placed on the "8" key). The placement of thumbs on keys was kept the same in both trial sets. The experimenter remained in the room during the experiment to ensure that participants maintained the instructed posture.

Each trial started with a warning tone of 400 Hz for 100-ms. Then a stimulus was presented above or below a fixation cross for 1500 ms. Participants responded to the stimulus shape by pressing the "2" or "8" key. An inter-trial interval of 1500 ms began immediately after a correct response or following a 500 ms visual error message ("Error") after participants pressed the wrong key or no response was detected. For each trial, the fixation cross was presented on the center of the screen all the time. Participants performed a set of 100 trials for each plane, the first 20 of which were excluded from the data analysis. The numbers of congruent and incongruent trials were equal and presented randomly within each set. For congruent trials, the stimulus location corresponded to that of the response that was to be made to the stimulus shape; for incongruent trials the stimulus location was in the noncorresponding position. Participants were told to keep their thumbs on the response buttons during the whole session and to respond to the stimuli as quickly and accurately as possible.

Results

Outliers, trials with RT < 100 ms or > 1000 ms (1.0%), and incorrect responses (1.8%) were excluded from the reaction-time (RT) analysis. A two-way analysis of variance (ANOVA) was conducted on the mean RT and percentage error (PE) data (see Table 1), with response-device orientation (transverse vs. frontal) and congruency (congruent vs. incongruent) as within-subject factors.

Table 1 Mean reaction time (in ms) and percentage error as a function of response-device plane and congruency in Experiments 1–4

Plane	Reaction time		Percentage error	
	Congruent	Incongruent	Congruent	Incongruent
Experiment 1				
Frontal	455 (11.6)	483 (10.7)	1.6 (0.6)	1.8 (0.5)
Transverse	446 (11.2)	470 (9.2)	1.1 (0.4)	2.8 (0.6)
Experiment 2				
Frontal	453 (13.8)	467 (13.5)	1.8 (2.1)	3.0 (3.4)
Transverse	451 (13.8)	457 (13.5)	2.1 (3.3)	2.9 (3.8)
Experiment 3				
Frontal	462 (17.6)	472 (15.2)	2.6 (4.5)	3.2 (4.5)
Transverse	467 (16.3)	467 (14.4)	2.5 (2.9)	3.5 (4.0)
Experiment 4				
Frontal	464 (13.9)	470 (15.1)	3.1 (0.5)	3.5 (0.9)
Transverse	464 (12.9)	469 (12.7)	2.0 (0.5)	2.6 (0.8)

Standard error of the mean in parentheses

Reaction time

The main effect of response-device orientation was not significant, $F_{(1,23)} = 1.16$, $p = .293$, $\eta^2 = 0.048$. Mean RT was similar when the device was held in the frontal plane ($M = 469$ ms) and the transverse plane ($M = 458$ ms). There was a Simon effect, $F_{(1,23)} = 45.25$, $p < .001$, $\eta^2 = 0.663$: RT was longer for incongruent trials ($M = 477$ ms) than for congruent trials ($M = 451$ ms). The two-way interaction of congruency and response-device orientation was not significant, $F_{(1,23)} < 1.0$. The Simon effect was 28 ms in the frontal plane, $F_{(1,23)} = 36.96$, $p < .001$, $\eta^2 = 0.616$, and 26 ms in the transverse plane, $F_{(1,23)} = 24.25$, $p < .001$, $\eta^2 = 0.513$, respectively. This pattern of results was also evident if only the first trial block, which had an equal number of trials to the transfer Simon task blocks in Experiments 2–4, was analyzed: The main effect of congruency in that block was significant, $F_{(1,23)} = 21.40$, $p < .001$, $\eta^2 = 0.493$, with significant Simon effects of 27 ms on the transverse plane and 20 ms on the frontal plane.

Percentage error

The main effect of the response-device orientation was not significant, $F_{(1,23)} < 1.0$: PEs were 1.7 and 2.0% when responding on the frontal and transverse planes, respectively. The PE of the incongruent trials ($M = 2.7\%$) tended to be larger than that of congruent trials ($M = 1.4\%$), but the main effect of congruency was not significant, $F_{(1,23)} = 3.03$, $p = .095$, $\eta^2 = 0.116$. The interaction between response-device orientation and congruency did not attain statistical significance, $F_{(1,23)} = 3.93$, $p = .060$, $\eta^2 = 0.146$, with the Simon effect being numerically smaller on the frontal plane ($M = 0.2\%$; $F_{(1,23)} < 1$) than on the transverse plane ($M = 1.7\%$, $F_{(1,23)} = 2.76$, $p = .110$, $\eta^2 = 0.107$).

Discussion

The results of Experiment 1 showed no statistical difference in size of the Simon effects obtained when the response device was held in the transverse or frontal plane. Moreover, any tendency was toward a larger effect in the transverse plane, which is opposite of what would be expected if participants were translating the up and down stimulus locations into far and near response locations. Thus, the results of Experiment 1 provide no evidence of an additional translation of mapping being performed when the number pad was held in the transverse plane.

Experiment 2

Experiment 1 showed no significant differences in the vertical Simon effect when the response device was oriented vertically in the frontal plane or horizontally in the transverse plane. Experiment 2 was designed to be similar to Conde et al.'s (2015) conditions, where participants completed a practice set responding to up and down stimulus locations with an incompatible mapping to response locations. Subsequently, they performed a vertical Simon task in a transfer set. One group of participants carried out the task with the device oriented in the frontal plane for both sets, as in Conde et al.'s experiment. For the other group, the device was oriented in the transverse plane for both sets. Based on Conde et al.'s translation explanation, there should be a transfer effect from the incompatible spatial mapping (i.e., the Simon effect should be eliminated) with the response device in the frontal plane but not with it in the transverse plane.

Methods

Participants

48 new participants (20 male; 43 right-handed and 5 left-handed) were recruited from the same subject pool as Experiment 1. No participant exceeded the 10% PE criterion for exclusion. All participants had normal or corrected-to-normal vision and were naïve to the experiment's purpose.

Stimuli and apparatus

The stimuli and apparatus for the transfer sets were the same as described in Experiment 1. Stimuli in the practice set were solid black circles of 0.5° diameter presented in the locations 6.5° above and below the fixation cross. The response configurations used in the practice set was the same as that described earlier for the transfer set in Experiment 1.

Procedure

Each participant performed 100 trials of an incompatible spatial practice task first. After a 5-min break, they performed 100 trials of a visual Simon task (the first 20 of which were regarded as warm-up and not included in analysis). Participants were instructed to hold the response number pad in the same plane for both the practice set and Simon transfer set. Half held the number pad vertically (in a frontal plane), whereas, the other half held the number pad horizontally (in a transverse plane). Participants were encouraged to have a walk outside the experiment room during each break, but many chose to stay in the room.

The timing sequence of practice trials was almost the same as the Simon task trials except that participants were told to respond to the location of the solid circle based on a spatially incompatible map (pressing “2” for above circle or pressing “8” for below circle). The Simon task trials were presented in the same way as Experiment 1.

Results

The data from the practice set and Simon transfer set were analyzed separately. The criteria of data trimming in Experiment 1 were applied both for the practice set and Simon transfer set.

Practice set

A one-way ANOVA with response-device orientation as the between-subjects factor was conducted on RT and PE. Trials with incorrect responses (5.3%) or RT < 100 ms or > 1000 ms (1.4%) were excluded from analysis of RT. The main effect of response-device orientation was not significant for RT, $F_{(1,46)} < 1$ ($M = 423$ ms for the frontal plane and 412 ms for the transverse plane). However, for PE the main effect of response-device orientation approached the 0.05 level, $F_{(1,46)} = 3.24$, $p = .078$, $\eta^2 = 0.008$, with PE tending to be larger for the frontal plane ($M = 6.6\%$) than transverse plane ($M = 4.0\%$).

Simon transfer set

Errors were made on 2.5% of the trials, and 1.4% of trials were excluded from RT analysis for being < 100 ms or > 1000 ms. A two-way ANOVA was performed for both RT and PE, with response-device orientation as a between-subjects factor and congruency as a within-subjects factor.

The main effect of response-device orientation was not significant for RT, $F_{(1,46)} < 1.0$ (mean RT on the frontal plane of 460 ms and transverse plane of 454 ms). The main effect of congruency was significant, $F_{(1,46)} = 4.71$, $p = .035$, $\eta^2 = 0.093$, indicating an overall Simon effect of 10 ms (mean RT on congruent trials of 452 ms and on incongruent trials of 462 ms). Response-device orientation and congruency did not interact, $F_{(1,46)} < 1.0$, but the Simon effect was a nonsignificant 6 ms on the transverse plane, $F_{(1,23)} < 1.0$, and a significant 14 ms on the frontal plane, $F_{(1,23)} = 4.27$, $p = .05$, $\eta^2 = 0.157$.

The PE was similar for the transverse ($M = 2.5\%$) and frontal planes ($M = 2.4\%$), $F_{(1,46)} < 1.0$. The PE tended to be less for congruent trials ($M = 2.0\%$) than for incongruent trials ($M = 3.0\%$), $F_{(1,46)} = 3.51$, $p = .068$, $\eta^2 = 0.071$. Like the RT results, the interaction between the orientation of the response device and congruency was not significant for PE, $F_{(1,46)} < 1.0$.

Discussion

Compared to Experiment 1 (Simon effects of 28 and 25 ms for the frontal and transverse planes), 100 practice trials with an incompatible spatial mapping reduced the Simon effect in the transfer set when practice and test were both with the device positioned in the frontal plane (14 ms) or the transverse plane (6 ms). The reduction of the Simon effect in the frontal plane replicates the result found by Conde et al. (2015), although the Simon effect was still significant. The continued presence of a small Simon effect in our experiment and not theirs may be due to the use of different response devices and postures in the two studies. Transfer of the incompatible mapping to the Simon task was at least as strong when the response-device was oriented in the transverse plane, orthogonal to the plane of the stimulus display, as when it was oriented in the frontal plane, counter to what would be expected based on Conde et al.’s translation explanation.

Experiment 3

In Experiment 2, an overall Simon effect remained when the Simon task was performed after 100 incompatible practice trials. Although there was no significant interaction of congruency with response-device plane, the frontal-plane condition tended to contribute more to the effect than the transverse-plane condition. We conducted Experiment 3 similarly to Experiment 2 but with a within-subjects design to assess whether this difference would be more evident if responses were made by the same participants with each response-device orientation.

Methods

Participants

24 new students (14 male; all right-handed) were recruited from the same subject pool as Experiment 1. Three additional participants were omitted for exceeding the 10% PE criterion. All participants had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Stimuli, apparatus, and procedure

All stimuli and apparatus were the same as Experiment 2. The difference was that participants were required to perform the practice and transfer tasks in both the transverse and frontal planes. Each participant performed a practice set of 100 trials with incompatible spatial mapping in one of the response-device orientations, took a 5-min break, and performed a Simon transfer trial set using the same response-device orientation. After another 5-min break, they then went through the same procedure for the other response-device orientation. The sequence of the frontal plane and transverse plane was counterbalanced between subjects.

Results

Practice set

The only factor, response-device orientation, was within-subjects. Trials for which the response was incorrect (2.4%) and trials for which RT was < 100 ms or > 1000 ms (0.3%) were removed from the RT analysis. A one-way ANOVA showed a nonsignificant main effect of response-device orientation on RT, $F_{(1,23)} = 3.22$, $p = .086$, $\eta^2 = 0.123$, with RT tending to be longer for responses made in the frontal plane ($M = 405$ ms) than transverse plane ($M = 386$ ms). The main effect of response-device orientation on PE was significant, $F_{(1,23)} = 4.28$, $p = .05$, $\eta^2 = 0.157$; counter to the RT tendency, the PE was less on the frontal plane ($M = 1.9\%$) than on the transverse plane ($M = 2.8\%$).

Simon task set

2.3% of the trials on which the response was incorrect and 0.9% of the trials for which responses were < 100 ms or > 1000 ms were excluded from the RT analysis. Response-device orientation and congruency both were within-subject factors.

The main effect of response-device orientation on RT was not significant, $F_{(1,23)} < 1.0$ (mean RT on both planes was 467 ms). Mean RT of the incongruent condition (470 ms) was similar to that of the congruent condition (465 ms), $F_{(1,23)} < 1.0$, showing no overall Simon effect. The interaction between response-device orientation and congruency was significant, $F_{(1,23)} = 4.48$, $p = .045$, $\eta^2 = 0.163$. As was shown numerically in Experiment 2, there was a 10-ms Simon effect for the frontal response-device orientation but no such effect ($M = 0$ ms) for the transverse response-device orientation.

Orientation of response device did not have a significant effect on PE, $F_{(1,23)} < 1.0$. The PE when responding on the transverse plane ($M = 3.0\%$) was similar to that of responding on the frontal plane ($M = 2.9\%$). For congruency, the PE of the incongruent condition ($M = 3.4\%$) was numerically larger than that of the incongruent condition ($M = 2.6\%$), but the main effect of congruency was not significant, $F_{(1,23)} < 1.0$. No significant interaction between response-device orientation and congruency was found, $F_{(1,23)} < 1.0$.

First block of Simon task

Whether response-device orientation was in the frontal or transverse plane was counterbalanced for order, so the 1st blocks were equivalent to those of Experiment 2 in which response-device orientation was a between-subject factor. Consequently, we compared the results of the 12 participants who received the transverse orientation first with those of the 12 participants who received the frontal condition first.

The main effect of response-device orientation was not significant, $F_{(1,22)} < 1.0$: RT for responding on the frontal plane ($M = 469$ ms) was similar to that for responding on the transverse plane ($M = 462$ ms). RT on congruent trials ($M = 463$ ms) was not much faster than that on incongruent trials ($M = 468$ ms). However, there was an interaction of congruency and response-device orientation, $F_{(1,22)} = 4.82$, $p = .039$, $\eta^2 = 0.180$: The Simon effect on the transverse plane was reversed numerically after incompatible practice (− 7 ms; $F_{(1,11)} < 1$), whereas the Simon effect on the frontal plane was still large (18 ms; $F_{(1,11)} = 6.91$, $p = .023$, $\eta^2 = 0.386$). The RT data thus bear out the results for the Simon effect even more strongly than the results of the between-subject comparison in Experiment 2.

Both the main effects of response-device orientation and congruency were not significant for PE. When responding on the transverse plane ($M = 3.4\%$), it was similar to that when responding on the frontal plane ($M = 3.0\%$), $F_{(1,22)} < 1.0$. PE in congruent trials ($M = 2.8\%$) was similar to that in incongruent trials ($M = 3.6\%$), $F_{(1,22)} < 1.0$. There also was no significant interaction between congruency and response-device orientation, $F_{(1,22)} < 1.0$.

Experiment 1 vs. Experiment 3

To inspect whether the Simon effect was indeed reduced by the prior practice with the incompatible mapping, results of Experiment 1 and Experiment 3 were compared. ANOVAs for RT and PE had 3 factors, 2 (response-device plane: transverse vs. frontal) × 2 (congruency: congruent vs. incongruent) × 2 (practice: practice vs. no-practice), with the first two factors being within-subjects and the third one being between-subjects.

Across the two experiments, response-device orientation and practice, $Fs_{(1,46)} < 1$, did not show any significant main effect on RT. The RT of incongruent trials ($M = 472$ ms) was longer than that of congruent trials ($M = 456$ ms), $F_{(1,46)} = 21.38$, $p < .001$, $\eta^2 = 0.317$. Congruency interacted with practice, $F_{(1,46)} = 11.22$, $p = .002$, $\eta^2 = 0.196$, reflecting that the Simon effect was larger in Experiment 1 without the prior incompatible practice ($M = 26.5$ ms) than in Experiment 3 with that practice ($M = 5$ ms), meaning that the overall Simon effect was reduced after spatially incompatible practice. The interaction between response-device orientation and congruency approached the 0.05 level, $F_{(1,46)} = 3.26, p = .078, \eta^2 = 0.066$, due to Simon effect tending to be smaller when the response-device orientation was in the transverse plane ($M = 13$ ms) rather than the frontal plane ($M = 19$ ms). No interaction between response-device orientation and practice was found, $F_{(1,46)} < 1.0$, and more important, no three-way interaction, $F_{(1,46)} < 1.0$.

No significant effects were found on PE. Only the main effect of congruency yielded a p value of < 0.10, $F_{(1,46)} = 3.19$, $p = .081$, $\eta^2 = 0.065$, indicating a tendency toward a Simon effect overall in the PE data.

Discussion

The comparison between the Simon effects obtained from Experiments 1 and 3 showed that spatially incompatible practice reduced vertical Simon effects in a significant amount no matter whether responding on the transverse or frontal plane. This result offers convincing evidence that orientation of the response-device is not crucial for the transfer of the spatially incompatible practice.

Experiment 4

Both Experiments 2 and 3 showed that 100 trials of practice with a spatially incompatible mapping can reduce the Simon effect when the response device is positioned along the transverse plane in both practice and transfer sets. Moreover, there was a tendency throughout for the Simon effect to be reduced to a lesser extent when responses were made on the frontal plane than on the transverse plane. In Experiment 4 we had participants practice with the incompatible spatial mapping with one response-device orientation and then perform the Simon task with the other response-device orientation. These conditions allowed determination of whether transfer occurs equally across the two response planes, which would be expected if there is no translation when responding in either, and whether the tendency toward lesser transfer resides in processes associated with practice or with transfer.

Methods

Participants

24 new students (16 male; 17 right-handed, 3 left-handed, and 4 ambidextrous) from the same subject pool participated. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Stimuli, apparatus and procedure

All stimuli and apparatus were the same as the prior experiments. All participants were asked to complete two parts, which was the same as Experiment 3. One part was responding on the frontal plane for the spatially incompatible practice task and then on the transverse plane while performing the Simon transfer task. The other part was responding on the transverse plane while performing the incompatible spatial practice task and then on the frontal plane for the Simon transfer task. Participants ran one part first and then the other after a 5-min delay. Order was counterbalanced between subjects.

Results

Practice set

2.6% of the trials for which responses were incorrect and 0.5% of the trials for which RT was < 100 ms or > 1000 ms were removed from the RT data. A one-way within-subject-design ANOVA was used to analyse the data. The main effect of response-device orientation on RT was not significant, $F_{(1,23)} < 1.0$. Mean RT was 388 ms when responses were made on the frontal plane and 393 ms on the transverse plane. The main effect of response-device orientation on PE was not significant, $F_{(1,23)} < 1$. The PE on frontal plane ($M = 2.7\%$) was similar to that on transverse plane ($M = 2.5\%$).

Simon task set

2.8% of the trials for which responses were incorrect and 1.5% of the trials for which RT was < 100 ms or > 1000 ms were excluded from RT analysis. A two-way ANOVA, with response-device orientation during the Simon task and congruency as within-subject factors, was used to analyze the data.

No significant effect of response-device orientation was found on RT, $F_{(1,23)} < 1.0$ (mean RT of 467 ms for frontal plane and 467 ms for transverse plane). A main effect of congruency was not evident, $F_{(1,23)} = 1.36$, $p = .256$, $\eta^2 = 0.056$. The mean RTs of incongruent trials (470 ms) and congruent trials (464 ms) were similar, indicating a reduction of the Simon effect after practice with a spatially incompatible practice. No significant interaction between response-device orientation and congruency was found, $F_{(1,23)} < 1.0$. The Simon effect was not significant when responding was made with the device oriented in the frontal plane of 6 ms, $F_{(1,23)} < 1.0$, or transverse plane, 5 ms, $F_{(1,23)} = 1.32$, $p = .261$, $\eta^2 = 0.054$.

Response-device orientation showed a significant effect on PE, $F_{(1,23)} = 5.69$, $p = .026$, $\eta^2 = 0.198$. The PE of responding during the Simon task on the frontal plane ($M = 3.3\%$) was larger than that of responding on the transverse plane ($M = 2.3\%$). The main effect of congruency was not significant, $F_{(1,23)} < 1$ (PE of incongruent trials was 3.0% compared to 2.6% for congruent trials). The interaction between response-device orientation and congruency was also not significant, $F_{(1,23)} < 1$. Further analysis showed that both Simon effects on the frontal and transverse planes were not significant (frontal plane, 0.4%, $F_{(1,23)} < 1$; transverse plane, 0.6%, $F_{(1,23)} < 1$).

Discussion

In Experiments 2 and 3, the response-device orientation in the practice set was in the same orientation as for the Simon transfer set, while in Experiment 4 the response-device orientation in the practice and Simon transfer sets differed. Yet, the vertical Simon effect was reduced in both cases. Experiment 4 provides further evidence that orientation of the response-device is not an important factor for producing the transfer effect with practice with the spatially incompatible mapping. Thus, our findings suggest that the responses are not coded differently when responding is made with the keypad device oriented in the two planes.

General discussion

The present experiments evaluated Conde et al.'s (2015) conjecture that, when placed flat along the transverse plane, vertically aligned response keys are coded as near and far with respect to a distance dimension. This depth coding of responses necessitates a translation from the vertically aligned stimuli displayed on a monitor in the frontal plane. In all of the present experiments, participants responded with a hand-held numeric keypad and pressed the keys with their thumbs. Experiment 1 showed that the basic Simon effect did not differ significantly between orientations of the keypad in the transverse and frontal planes. Experiments 2 and 3 showed transfer effects of prior practice with an incompatible spatial mapping for both transverse and frontal orientations of the keypad, when the orientation was the same for the practice and transfer sets. Likewise, Experiment 4 showed that transfer occurred when the incompatible practice was performed with the response device in the transverse plane and the transfer Simon task in the frontal plane, and vice versa. Thus, under the conditions of the present study, the obtained results are consistent with the view that responses are coded as bottom and top in the transverse plane as well as in the frontal plane.

This conclusion is in agreement with terminology used to describe relations on keyboards. For the alphabetic keys of a QWERTY keyboard, the home row is the center of the three rows of keys on which a typist is to place the fingers. "The top row keys are the ten keys found above the home row keys…", and "The bottom row keys are the ten keys found below the home row keys…" (Computer Hope 2017). The function keys are described similarly: "The function keys, also called the F-keys or Fn keys, are located in the top row of nearly all computer keyboards" (PC Help Center 2013). Although everyday usage is not decisive regarding how locations are being coded, the implication is that it is more natural for people to think of the keys as located at top or bottom rather than as far or near.

The conclusion that depth relations are not critical when stimuli vary in vertical position also is in agreement with empirical studies. Vu et al. (2000, Experiment 1A) examined two-choice tasks in which possible stimulus locations in a trial block were at diagonal locations on an imaginary square (top-left or bottom-right in some blocks and top-right or bottom-left in others). By varying diagonal locations and mappings of response keys, conditions allowed compatibility on the vertical dimension, horizontal dimension, or both. For present purposes, of most importance is that responses were made with the thumbs on a numeric keypad, as in the present study, and the keypad was held horizontally (the transverse plane) or vertically (the frontal plane). Orientation of the response device did not enter into any significant effects for either RT or PE. Even more directly, a control experiment for standard two-choice tasks in the horizontal and vertical dimensions (Vu et al. 2000, Experiment 1B), with stimuli and responses in left and right locations for the former and top and bottom locations for the latter, showed no difference in SRC effects and no influence of response-device orientation.

In contrast, depth coding of responses along the transverse plane is evident in experiments by Rigon et al. (2011) and Umemura (2015) in which stimuli varied in the depth dimension of a 3-dimensional (3-D) display. Rigon et al. found that near and far keypress responses yielded a Simon effect when the stimulus locations were near or far but not when they were left or right on the horizontal dimension. Umemura (2015) displayed stimuli on a ground or ceiling plane in 3-D space such that they also created an upper vs. lower distinction, which varied as a function of ground vs. ceiling in the 2-dimensional (2-D) image plane. Responses were push and pull movements of a joystick placed on a table in front of the participant's midline. Umemura also found a 3-D Simon effect but, more important, an additional 2-D vertical Simon effect that did not interact with the 3-D Simon effect. The independence of the 2-D effect from the 3-D effect implies two separate response codes, one for top–bottom and the other for near-far. Because the stimuli in our study varied in location only along the vertical dimension, one would expect a Simon effect based on vertical response coding, as our evidence suggests.

Umemura (2015) included a comparison of conditions with or without a 3-D monocular texture-gradient depth cue in addition to binocular disparity and found no significant influence of the texture cue on the 3-D or 2-D Simon effect. Additional evidence that monocular depth cues in displays do not generate near-far coding of responses is apparent from studies by Markman and Brendl (2005) and Proctor and Zhang (2010). In the former study, a positive or negative word was displayed above or below a bar in the middle that contained the participant's name; 3-D perspective cues depicted a word in the top location as farther away than a word in the bottom location, participants responded with toward or away joystick movements in the transverse plane. Instructions were to move the word toward or away from the bar with the mapping positive-toward/negative-away or positive-away/negative-toward. The former mapping yielded better performance than the latter, which Brendl and Markman interpreted as approach/avoidance reactions to the representation of self (the bar). However, Proctor and Zhang conducted variants of the task and showed that one's name did not have to be on the bar and that results were similar with the perspective depth cues removed and the mapping was of vertical position in the frontal plane to joystick movement in the transverse plane.

Why is it that people tend to code the response locations on a keyboard or keypad as top and bottom when interacting with a 2-D display? The answer may lie in a what is sometimes called directional stimulus–response compatibility (Worringham and Beringer 1998), in which a person is to move a control in a particular direction to produce movement of a visual element (e.g., a cursor) in a specific direction. Worringham and Beringer (1998, 1989) tested people in various conditions in which they were facing a visual display but with the body turned 90° sideways in some cases to operate a joystick located behind them or to the left or right side. They were to move the joystick to produce leftward or rightward movement on the display with different mappings of control direction to cursor direction. Of three possible types of compatibility identified by Worringham and Beringer, only what they called visual-field compatibility exerted a significant effect on performance. A situation that is visual-field compatible "is one in which the motion of the relevant limb segment is in the same direction as that of the 'controlled element', or 'display', as seen in the visual field" (Worringham and Beringer 1998, p. 867). The contribution of visual-field compatibility has been shown to be sufficiently robust to now be called the Worringham and Beringer principle (Chan and Hoffmann 2012).

Although there is no movement of a response device or visual element in any direction for the situations studied in the present experiments, it appears that participants are using the same frame of reference for the keypad aligned horizontally as they would if it were aligned vertically. In other words, the response alternatives are coded as top and bottom. This may occur in part because a person's vantage point when looking down on a keypad is from above. Although the keypad does extend away from the individual, the predominant view from above is one of top and bottom of the device. This vantage point applies as well to everyday use of a computer keyboard, which to reiterate, is described as top and bottom. There is even a trend in our data for the effects to be slightly larger with the horizontal, transverse device orientation, which suggests that the arrangement of response alternatives on that dimension may in fact be slightly more compatible (or natural) than a vertical, frontal device orientation, possibly due to our experience of pressing keys with this relation.

A question that remains is why Vu (2007), when having participants respond with the response-device aligned on a transverse plane, did not find any influence of 72 practice trials with an incompatible mapping on performance of a subsequent Simon task. It was possible to obtain transfer with Vu's methodology if more practice trials were experienced, because it was evident with 600 practice trials in her Experiment 2. A similar pattern was obtained by Proctor et al. (2007) with left–right auditory stimuli, where transfer of an incompatible spatial mapping of tone locations to the Simon task for tone pitches was not apparent after 84 trials but was clear after 300 or 600 incompatible trials. Other studies have also found relatively broad transfer across stimulus–response modalities and tasks when the incompatible-mapping practice that precedes the test series is several hundred trials (Marini et al. 2011; Ottoboni et al. 2013; Proctor et al. 2009).

Differences between Vu's (2007) study and the present one include the following: the 72 practice trials in her experiment using limited practice was only about 72% of that of the present study (and of Conde et al. 2015); the Simon task required a red–green color discrimination as opposed to the circle–square form discrimination; the Simon task and incompatible practice used identical stimuli (including the red–green color difference) compared to stimuli that varied in both shape and color; the keypress responses were made with the index fingers on the numeric pad of a computer keyboard placed on a table top rather than with the thumbs on a hand-held numeric pad. Which if any of these factors might be crucial is unknown. One possibility is the response arrangement. To place the index fingers on the keys, as in Vu's study, one hand has to be elevated somewhat relative to the other; this placement seems less natural than holding a keypad with the thumbs on the keys or having hands to their natural left or right sides operating the keys, as in Conde et al.'s study. The difficulty of the response situation could increase the amount of practice that is needed for the associations between incongruent responses to become sufficiently strong to significantly affect performance on the subsequent Simon task.

Conclusion

The present study replicated Conde et al.'s (2015) finding of a reduced Simon effect for vertically oriented stimulus and response arrays when responding in the frontal plane. This result was also evident when responding in the transverse plane, providing no evidence that, when responding on a hand-held numeric keypad, the vertical positions of responses along the transverse plane are coded as far and near rather than top and bottom. In addition, the Simon effect in the transverse plane was of similar size to that obtained in the frontal plane, and the transfer effects between-planes of prior practice with an incompatible spatial mapping are just as large. These results are in contrast to Conde et al.'s translation hypothesis but are consistent with that expected with vertical coding shown in prior research and everyday labeling of keyboard rows. Why Vu (2007) found transfer when responding in the transverse plane only after longer amounts of practice than in the present study remains unclear.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

Ethical approval This research has been conducted in compliance with ethical standards, under an approved IRB protocol from Purdue University.

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