Is effector visibility critical for performance asymmetries in the Simon task? Evidence from hand- and foot-press responses

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Abstract

The Simon effect is a stimulus-response compatibility effect in which the spatial dimension of the stimulus is task-irrelevant. This effect is often larger in reaction time (RT) for the stimulus located on the dominant-hand side of participants, for most of which it is the right hand, due to dominant-hand keypress responses being faster than non-dominant-hand responses. Experiment 1 demonstrated that pedal-press responses with the left and right feet show a similar asymmetry, favoring the right response for right-footed persons. The asymmetric pattern for keypress responses was absent in results of Wallace (*Journal of Experimental Psychology*, 93, 163–168, 1972) when participants were not permitted to see the response keys or their hands placed on the keys at any time during the experiment, whereas we found the asymmetric pattern in a recent study when participants placed their hands on the keys prior to their being covered up. Experiments 2 and 3 showed that the Simon effect asymmetry for RT was evident even when participants were prevented from seeing the response device and their responding hands or feet. Although both hands and feet showed a Simon effect asymmetry in RT, consideration of incorrect responses suggested that whereas the asymmetry for hands is not due to a response bias, that for the feet may be due at least in part to such bias. Regardless, our results suggest that the Simon effect asymmetry is mainly an artifact of comparing conditions for which one response is made by the faster dominant right effector and the other with the slower non-dominant left effector.

Keywords Foot responses · Handedness · Simon effect · Simon effect asymmetry

Introduction

The Simon effect is a widely studied spatial stimulus-response compatibility effect in which participants are to make a left or right keypress response to a relevant stimulus feature, often color, with the left or right stimulus location being task-irrelevant. Responses are typically more accurate when stimulus and response locations correspond than when they do not (Lu & Proctor, 1995; Simon, 1990). The Simon effect indicates that stimulus location is processed “automatically” in this task context, most likely because a left/right discrimination has

been defined for the responses (Ansorge & Wühr, 2004; Yamaguchi & Proctor, 2012).

A relatively common finding is that when left-hand responses are analyzed separately from right-hand responses, the Simon effect is larger for the stimulus location to the side of the participant’s dominant hand (Rubichi & Nicoletti, 2006; Spironelli, Tagliabue, & Umiltà, 2009; Tagliabue et al., 2007). Because the majority of people are right-handed, this result means that the difference in reaction times (RTs) for non-corresponding and corresponding trials will be larger for the right stimulus location (which corresponds with the right hand) than for the left stimulus location, even if participation is not restricted to right-handed individuals. The authors of the above-cited studies proposed that the Simon effect asymmetry is due to an attentional bias toward the operating space of the dominant effector, which results in stronger coding of the stimulus location in the visual hemifield.

Seibold, Chen, and Proctor (2016) replicated this pattern of results for the location-based Simon effect but not for a word-based Simon effect, for which the irrelevant location information is conveyed by the centered words *left* and *right* (Luo & Proctor, 2019). For right-handers responding to stimuli in

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physically left and right locations, Seibold et al. found faster responses for the right hand than the left hand overall, and provided evidence that the apparent Simon effect asymmetry is an artifact of this difference in response hand/location. That is, the Simon effect asymmetry could be accounted for entirely in terms of the difference in RTs for the left and right hands, which is reflected statistically in the main effect of response hand/location.

People also have a dominant foot that typically is used to perform manipulative actions (like kicking a ball), with the non-dominant foot used to provide stability (Gabbard & Hart, 1996). Foot dominance is highly correlated with hand dominance (e.g., Peters & Durling, 1979). Foot responses have been used occasionally in RT studies, with perhaps the closest study to a standard Simon task being that of Phillips and Ward (2002). They showed correspondence effects for the side to which object handles were oriented, but because their analysis did not report the results separately as a function-responding foot, whether the Simon effect asymmetry was evident cannot be evaluated. Because responses can be made faster with the dominant foot than with the non-dominant foot (Peters & Durling, 1979), the hypothesis that the Simon effect asymmetry is an artifact of this RT difference predicts that the asymmetry should be evident for the feet. However, we are not aware of any study of the standard Simon effect that has examined whether pedal-press responses with the feet yield a Simon effect asymmetry.

Wallace (1972) obtained results suggesting that the visual sensory input for the response hands and keys is critical for the Simon effect asymmetry. He conducted an experiment with a location-based Simon task, in which participants who were prevented from seeing the hands/keys during task performance did not show the asymmetric pattern, whereas participants tested under conditions in which they could see their hands did show the pattern. However, Seibold et al. (2016) reported an experiment in which half the participants performed the similar location-based Simon task with their hands (and the response keys) out of view, and the other half could see their hands and the keys during task performance. The Simon effect asymmetry did not differ in these two conditions, indicating that the lack of visual sensory input for the hand and key locations had no significant influence on the Simon effect asymmetry.

A difference between Wallace's (1972) experiment and that of Seibold et al. (2016) is that participants never saw the response keys or their hands placed on them at any stage of Wallace's experiment, whereas in Seibold et al.'s experiment the participants saw the keys and placed their hands on them prior to the hands being covered up. The difference in results of Wallace and Seibold et al. suggests the possibility that participants need to form a visuospatial representation of the response keys and their effectors in order to show the asymmetric Simon effect pattern. That is, seeing where the keys are

located and the hands placed on them prior to the experiment might be adequate for the responses to be represented spatially much as they would if they were visible throughout the experiment.

Purpose

The purpose of Experiment 1 was to determine whether foot dominance influences performance of the Simon task in a way similar to hand dominance. In it, we compared performance with hand- and foot-press responses when participants were allowed to see the response situation throughout the experiment. Experiments 2 and 3 aimed at further examining whether the Simon effect asymmetry depends on visibility of responding effectors and response devices. In Experiment 2, responses were hand presses, and the apparatus and hands on the keys were covered up during the experiment. The conditions differed in whether participants saw the apparatus and placed their hands on the response keys before being covered up or whether the cover was present when participants entered the room and place their hands on the keys. In Experiment 3, responses were foot presses and the apparatus and foot placement were not visible from the outset for one group. This group was compared to one that could see the response situation throughout the experiment. Thus, Experiment 1 allowed assessment of whether foot presses on pedals yield a Simon effect asymmetry as do hand presses with index fingers on keys, whereas Experiments 2 and 3 determined whether visual representation of the experimental situation has similar effects for the two different sets of response effectors.

Experiment 1: Hand presses on keys versus foot presses on pedals

Method

Participants Thirty-two students from RWTH Aachen University took part in the experiment for partial course credit. We included only the data of those 24 participants (three females, 21 males) with a mean age of 23.3 years ($SD = 7.9$) who were clearly right-handed and right-footed (not left-handed, left-footed, or ambidextrous) with a handedness score larger than 40 and a positive footedness score. Thus, as intended a priori, the overall sample size matched that of Experiment 1 of Seibold et al.'s (2016) study, which was conducted in the same context.

The mean handedness score of the 24 participants, measured by the Edinburgh handedness inventory (Oldfield, 1971) was 86.8. The mean footedness score was 13.7, measured by the Waterloo Footedness Questionnaire-Revised

(Elias, Bryden, & Bulman-Fleming, 1998) translated into German.

Apparatus and stimuli The experiment was conducted under Mac OSX in MATLAB with the Psychtoolbox-3 extension. The monitor was viewed at a distance of approximately 60 cm. The spatial stimuli were red and green rectangles of $1.2^\circ \times 0.9^\circ$ visual angle displayed on the white background of the monitor. The stimuli could be presented in locations that were 4.5° visual angle to the left or right of a centered fixation cross ($0.8^\circ \times 0.8^\circ$). Left and right keypress responses executed with the index fingers were made on two keys of a response box (center-to-center key distance: 13 cm). Left and right pedal-press responses executed with the feet were made on the gas pedals of two driving simulator tools of Logitech Formula Force GP (center-to-center pedal distance: 25 cm).

Procedure Participants first completed the Edinburgh handedness inventory (Oldfield, 1971) and the Waterloo Footedness Questionnaire-Revised (Elias et al., 1998), translated into German. The experimental session included two blocks, which we call hand-response and foot-response, with the order of the blocks counterbalanced among participants. For the hand-response condition, participants responded by pressing the left or right key of the response box with the left or right index finger, respectively. For the foot-response condition, participants responded by pressing the left or right pedal with the appropriate foot. Each half of the experiment contained 12 practice trials, followed by 120 experimental trials with stimulus colors and locations randomly intermixed. The stimulus information and response location corresponded on 60 trials but not on the other 60 trials. Each trial started with a 1,000-ms presentation of the fixation cross, followed by a 100-ms warning tone (400 Hz). After that, the stimulus appeared and stayed on the screen until a response was registered. Following the response, a 500-ms feedback screen appeared that showed just the fixation cross for correct responses or the word “Error” at 2.40° below the fixation cross for incorrect responses.

Design The independent variables were stimulus location (left vs. right), response location (left vs. right), and effector (hands vs. feet; blocked), all of which were varied within participants. The dependent variables were RT and percentage error (PE).

Results

Reaction time We excluded trials with RTs above 900 ms and below 100 ms (2.5%), as well as error trials (3.4%) for the analysis of the RT, like Seibold et al. (2016) and Rubichi and Nicoletti (2006) did. An analysis of variance (ANOVA) was conducted on RT with stimulus location, response location, and effector as within-participants factors on RT. With the factors classified in this manner, the stimulus location $\times$

response location interaction reflects the Simon effect, which is the performance difference between the corresponding trials and the non-corresponding trials. In addition, the Simon effect asymmetry refers to the difference between the Simon effects (i.e., the stimulus location $\times$ response location interaction) for the stimulus locations, which is reflected statistically in the main effect of response location (see Table 1 of Seibold et al., 2016).

In addition to the null hypothesis significance testing (NHST) results, we report Bayes factors, BF_{10} (Rouder, Morey, Speckman, & Province, 2012), for non-significant effects in this experiment and the others. BF_{10} represents the ratio of the likelihood of the data under the alternative hypothesis (H_1) relative to that under the null hypothesis (H_0), and provides converging evidence in addition to NHST for nonsignificant effects. However, note that we are not making strong claims about there being absolutely no difference for the nonsignificant effects. Rather, in almost all cases, the patterns of results are similar for both performance conditions being compared. Specifically, we used the JASP statistics package (version 0.13; <https://jasp-stats.org/>) to calculate the Bayes factors, and interpret them based on Jeffreys’ cut-offs (Jeffreys, 1961, see also Jarosz & Wiley, 2014). Values of BF_{10} greater than 1 indicate evidence for the alternative hypothesis: Values between 1 and 3 indicate anecdotal evidence, values between 3 and 10 indicate substantial evidence, values between 10 and 30 strong evidence, values between 30 and 100 very strong evidence, and values greater than 100 decisive evidence. Values of BF_{10} less than 1 indicate evidence for the null hypothesis: Values between 0.33 and 1 indicate anecdotal evidence, values between 0.10 and 0.33 substantial evidence, values between 0.03 and 0.10 strong evidence, values between 0.01 and 0.03 very strong evidence, and values less than 0.01 decisive evidence.

The analysis showed a main effect of effector, $F(1, 23) = 65.30, p < .001, \eta_p^2 = .74$, with the hand-press responses being 67 ms faster than the foot-press responses ($M_s = 402$ ms vs. 469 ms). Response location interacted with stimulus location, $F(1, 23) = 103.44, p < .001, \eta_p^2 = .82$, indicating a significant Simon effect, but the response location main effect was also significant, $F(1, 23) = 12.98, p = .001, \eta_p^2 = .36$. This main effect reflects longer RTs for the left effector than the right effector, or alternatively, the presence of the Simon effect asymmetry. The Simon effect was smaller for the left stimulus location (19 ms, $p = .001$) than for the right stimulus location (45 ms, $p < .001$).

The three-way interaction of stimulus location $\times$ response location $\times$ effector was also significant, $F(1, 23) = 4.44, p = .046, \eta_p^2 = .162$. The Simon effect was slightly smaller when responding with the hands (27 ms) than when responding with the feet (37 ms; see Fig. 1). The main point, though, is that the Simon effect was evident for both the hand-response condition, $F(1, 23) = 72.38, p < .001, \eta_p^2 = .76$, and the foot-response condition, $F(1, 23) = 64.42, p < .001, \eta_p^2 = .74$.

Fig. 1 Reaction times (RTs) and percentage errors (PEs) depicted as a function of stimulus location (left vs. right), response location (left vs. right), and effector (hands vs. feet) in Experiment 1. The error bars reflect Cousineau-Morey confidence intervals (Morey, 2008)

More important, the response location $\times$ effector interaction, indicative of whether the asymmetry differed between the two response sets, was not significant, $F(1, 23) = 2.10$, $p = .161$, $\eta_p^2 = .08$, $BF_{10} = 0.37$. Both the hand-response and foot-response conditions showed significant main effects of response location. The right-hand responses were faster than the left-hand responses ($M_s = 397$ ms vs. 406 ms), $F(1, 23) = 6.03$, $p = .022$, $\eta_p^2 = .21$. Similarly, the right-foot responses were faster than the left-foot responses ($M_s = 460$ ms vs. 477 ms), $F(1, 23) = 9.45$, $p = .005$, $\eta_p^2 = .29$. Again, these main effects of response location translate to significant Simon effect asymmetries. The hand-response condition showed a larger Simon effect for the right stimuli (36 ms, $p < .001$) than for the left stimuli (19 ms, $p = .001$), as did the foot-response condition (right stimuli: 55 ms, $p < .001$; left stimuli: 20 ms, $p = .008$).

Percentage error An ANOVA with the same factors was conducted on the error rates. The Simon effect, indicated by a stimulus location $\times$ response location interaction, was also

significant for PE, $F(1, 23) = 10.66$, $p = .003$, $\eta_p^2 = .32$. There was no significant main effect of response location, $F < 1$, $BF_{10} = 0.16$, with an error rate of 3.1% for the left responses and 3.0% for the right responses. In other words, there was no evidence of a Simon effect asymmetry overall in the error data (Simon effects of 1.6%, $p = .007$ for the left stimulus location and 1.7%, $p = .011$ for the right stimulus location). The Simon effect was not modulated significantly by effector, $F < 1$, $BF_{10} = 0.47$, being 1.8% for foot responses and 1.5% for hand responses (see Fig. 1). Hand and foot responses did not differ significantly in PE, $F(1, 23) = 3.12$, $p = .091$, $\eta_p^2 = .12$, $BF_{10} = 0.59$, with an error rate of 2.7% for foot responses and 3.4% for hand responses. Stimulus location was modulated by effector, $F(1, 23) = 7.91$, $p = .010$, $\eta_p^2 = .26$. For hands, similar errors were obtained for left stimuli and right stimuli ($M_s = 3.5\%$ vs. 3.2%, $p = .609$, $BF_{10} = 0.23$), whereas for feet, fewer errors were obtained for left stimuli than right stimuli ($M_s = 2.3\%$ vs. 3.1%, $p = .050$).

Similarly, the effector interacted with response location, $F(1, 23) = 16.32$, $p = .001$, $\eta_p^2 = .42$. For the hands, fewer

errors were obtained for left responses than for right responses ($M_s = 2.7\%$ vs. 4.0% , $p = .014$), whereas for the feet, more errors were obtained for left responses than for right responses ($M_s = 3.4\%$ vs. 2.0% , $p = .003$). This significant interaction between response location and effector indicates that the two effectors had different degrees of Simon effect asymmetry in PE. Separate ANOVAs showed that for hand responses, the response location main effect was significant, with fewer errors for left responses than for right responses ($M_s = 2.74\%$ vs. 3.97%), $F(1, 23) = 7.09$, $p = .014$, $\eta_p^2 = .24$. Translating to the Simon effect asymmetry, the Simon effect was 2.8% ($p = .004$) for the left stimuli, larger than that of 0.3% ($p = .739$, $BF_{10} = 0.30$) for the right stimuli. For foot responses, the response location main effect was also significant, but in the opposite direction with fewer errors for right responses than for left responses ($M_s = 2.05\%$ vs. 3.39%), $F(1, 23) = 11.36$, $p = .003$, $\eta_p^2 = .33$. Translating to the Simon asymmetry effect, the Simon effect was 0.5% ($p = .471$, $BF_{10} = 0.36$) for the left stimuli smaller than that of 3.2% ($p < .001$) for the right stimuli.

Discussion

The hand responses showed a Simon effect asymmetry for RT similar to prior studies (Rubichi & Nicoletti, 2006; Seibold et al., 2016; Spironelli et al., 2009; Tagliabue et al., 2007), with the Simon effect in RT being larger for the right stimulus than for the left stimulus. The foot responses also showed a Simon effect asymmetry in RT, with the sample mean size being slightly larger than for the hand responses. The overall response location main effect in the RT analysis, coupled with the absence of significant interaction with response effector, signifies that the Simon effect asymmetry can be attributed to RT being less for right responses than for left responses. This pattern is consistent with the participants being both right-handed and right-footed. The PE data also showed a Simon effect that was not qualified by an interaction with response effector. For PE, though, response effector interacted separately with response location, as well as with stimulus location. The interaction with response location indicates that the Simon effect asymmetry differed between the hands and feet.

A natural question to ask is the extent to which the observed RT and PE differences could reflect a speed-accuracy tradeoff. The overall longer RT with the feet than with the hands could be due to a speed-accuracy tradeoff as the error rate was less for foot-press responses, although not significantly so. The relation between speed and accuracy for the left and right responses is trickier to understand because they are alternative responses in the same task (Krueger, 1983; Krueger & Allen, 1987). If faster right responses reflect a bias to respond “right,” then the false-right error rate (incorrectly responding right instead of left; shown as the PE for left responses) should be greater than or equal to the false-left error

rate (incorrectly responding left instead of right; shown as the PE for right responses).

The PE data for the hands showed no evidence for such bias to respond “right” because the false-right error rate (i.e., PE for left responses) was less than the false-left error rate (i.e., PE for right responses). However, for the feet, the error rate was higher for left responses than for right responses, indicating some bias to respond “right.” These results are supported by an analysis of balanced integration scores (BIS), which integrate speed and accuracy at equal weights (Liesefeld & Janczyk, 2019): The opposing directions of effects in speed and accuracy for the hands resulted in no significant difference between right and left hands on the BIS measure, $F(1, 23) = 2.20$, $p = .152$, $\eta_p^2 = .087$, $BF_{10} = 0.35$, whereas the supportive effects for the feet yielded a significant advantage for the right foot, $F(1, 23) = 21.01$, $p < .001$, $\eta_p^2 = .477$. A significant advantage for the right response in the BIS indicates that there is a bias to respond “right” when taking both RT and PE into account. We interpret the above results as suggesting that, for the hands, the Simon effect asymmetry in RT reflects a faster response execution for the right than left hand, whereas, for the feet, the RT asymmetry is due at least in part to a bias toward making the right response. This bias could account for why the Simon effect asymmetry in RT tended to be larger for the foot responses than for the hand responses.

Experiment 2: Prior visibility of response keys and hand placement

As described in the *Introduction*, Seibold et al. (2016) found the Simon effect still to be evident when participants performed with their hands and the response device covered, whereas Wallace (1972) did not. Because participants were allowed to place their hands on the visible response box in the former study but not the latter, we examined whether prior viewing of the response situation was critical in Experiment 2. All participants performed with hand responses, and none were able to see the response box or their hands placed on it as they performed the task. However, half of the participants saw the response box and their placement of the hands on the response keys at the start of the session, prior to their hands being covered, whereas the other half never saw the response box or their hands positioned on it. The question of interest was whether the Simon effect asymmetry would be present for the prior group of participants, as in Seibold et al.’s study, but absent for the latter group, as in Wallace’s study.

We initially tested 48 participants in Experiment 2a, using the same sample size as in Seibold et al.’s (2016) Experiment 2, but the statistical results regarding the influence of prior response-box/hand-placement visibility on the Simon effect asymmetry were equivocal. To increase the possibility of

detecting this effect that potentially was the source of the difference in Wallace's (1972) and Seibold et al.'s (2016) results, we tested another 48 participants in Experiment 2b and report the combined analysis.

Method

Participants There were in total 96 right-handed participants (48 female, 48 male; mean age = 19.1 years, $SD = 1.8$), with a mean handedness score (Oldfield, 1971) of 89.1. They were randomly assigned to the prior response hands/device visibility condition (with vs. without prior visibility; between-participants). They were undergraduate students enrolled in the introductory psychology courses at Purdue University who received course credit for participating.

Apparatus, stimuli, and procedure The experiment was run on a Dell Optiplex 745 personal computer with a Dell 19-in. LCD color monitor. Stimulus presentation, response recording, and feedback were controlled by E-prime 2.0 software. The spatial stimuli were red and green rectangles of $1.1^\circ \times 0.9^\circ$ visual angle, presented 3.8° to the left or right of a centered fixation cross ($0.7^\circ \times 0.7^\circ$). The stimuli were displayed on a white background. During the session, the response box was placed under a black wooden box, with the computer monitor located on top of the wooden box. Participants were seated in front of the monitor with a distance of approximately 60 cm, and they were required to respond by pressing the left-most and right-most buttons on the response box (center-to-center key distance: 7.8 cm). A black cloth hung over the front (on the side facing the participant) of the wooden box throughout the session to prevent participants from seeing the box or their hands as they performed the task. Each participant performed the Simon task in this situation for 12 practice trials and 120 experimental trials.

Each participant performed under one of the two prior visibility conditions, seeing or not seeing the response device and their hands placed on it prior to performing the task with them covered. In the condition with prior visibility, the black cloth was not in place when the participant entered the experiment cubicle, and the participant placed the index fingers on the outer keys of the visible response box. Then the cloth was lowered into place so that the hands and response box were covered during the session. In the condition without prior visibility, the black cloth was already in place when the participant entered the experiment cubicle. The participant was instructed to place the hands under the cloth at the far sides of the box, and then move them in until they could locate the outer keys of the row, on which they were to place their index fingers. In this condition, participants did not see the response box or the positioning of their hands on it at any time during the experiment.

Design The independent variables were stimulus location (left vs. right; within-participants), response location (left vs. right; within-participants), prior visibility (with vs. without; between-participants), and experiment (Experiment 2a vs. 2b; between-participants). The dependent variables were RT and PE.

Results

Reaction time Error trials (2.5%), and trials with RT above 900 ms and below 100 ms (1.0%) were excluded from the RT analysis as in Experiment 1. Results showed a stimulus location $\times$ response location interaction, $F(1, 92) = 27.64$, $p < .001$, $\eta_p^2 = .23$, indicating a significant Simon effect (see Fig. 2). There was also a main effect of response location, $F(1, 92) = 24.52$, $p < .001$, $\eta_p^2 = .21$, with the right responses being 12 ms faster than the left responses ($M_s = 428$ ms vs. 416 ms). This main effect of response location signaled a significant Simon effect asymmetry (Seibold et al., 2016). The Simon effect was 26 ms for the right-located stimulus, $p < .001$, and 0 ms for the left-located stimulus, $p = .876$, $BF_{10} = 0.15$. Neither of these effects interacted significantly with experiment, stimulus location $\times$ response location $\times$ experiment, $F < 1.0$, $BF_{10} = 0.33$, and response location $\times$ experiment, $F(1, 92) = 3.25$, $p = .075$, $\eta_p^2 = .03$, $BF_{10} = 1.04$. The latter term reflects a nonsignificant tendency for a larger advantage for the right response in Experiment 2a (17 ms) than in Experiment 2b (8 ms), though separate analyses showed the response location effect to be significant for each experiment (Experiment 2a: $p < .001$; Experiment 2b: $p = .028$).

No other effects in the main analysis were significant. The only ones to yield F ratios greater than 1.0 were the main effect of stimulus location, $F(1, 92) = 1.65$, $p = .203$, $\eta_p^2 = .02$, $BF_{10} = 0.17$, the stimulus location $\times$ prior visibility $\times$ experiment interaction, $F(1, 92) = 1.17$, $p = .283$, $\eta_p^2 = .01$, $BF_{10} = 0.27$, and, most important, the response location $\times$ prior visibility interaction, $F(1, 92) = 1.30$, $p = .257$, $\eta_p^2 = .01$, $BF_{10} = 0.34$.

To verify the presence of the Simon effect asymmetry in both visibility conditions, we conducted separate ANOVAs for each prior-visibility condition. The main effect of response location was significant in both prior visibility conditions. With prior visibility, right responses were faster than left responses ($M_s = 416$ ms vs. 432 ms), $F(1, 47) = 23.36$, $p < .001$, $\eta_p^2 = .33$. Without prior visibility, right responses were also faster than left responses ($M_s = 415$ ms vs. 425 ms), $F(1, 47) = 5.83$, $p = .020$, $\eta_p^2 = .11$. Translating to the Simon effect asymmetry, it was significant both with prior visibility (left stimulus: -4 ms, $p = .426$, $BF_{10} = 0.29$; right stimulus: 27 ms, $p < .001$), and without prior visibility (left stimulus: 6 ms, $p = .276$, $BF_{10} = 0.38$; right stimulus: 25 ms, $p < .001$).

Fig. 2 Mean reaction times (RTs) and percentage errors (PEs) as a function of stimulus location (left vs. right), response location (left vs. right), and prior hand visibility (with vs. without) of the response box and hands

Percentage error The PE data showed neither a stimulus location $\times$ response location interaction, $F(1, 92) = 1.82$, $p = .180$, $\eta_p^2 = .02$, $BF_{10} = 0.61$, nor a three-way interaction of those variables with visibility condition, $F < 1.0$, $BF_{10} = 0.20$. Thus, there was no overall Simon effect in PE (see Fig. 2). The main effect of response location was also nonsignificant, $F(1, 92) = 1.15$, $p = .286$, $\eta_p^2 = .01$, $BF_{10} = .16$, providing little evidence of a Simon effect asymmetry. However, the one significant interaction was that of response location $\times$ prior visibility, $F(1, 92) = 4.77$, $p = .031$, $\eta_p^2 = .05$. Separate ANOVAs showed that the main effect of response location was not significant for PE when the hands were visible in advance, with similar error rates for the right and left responses ($M_s = 2.3\%$ vs. 2.6%), $F < 1$, $BF_{10} = 0.19$, but more errors were found for right responses than for left responses ($M_s = 2.9\%$ vs. 2.0%) when the hands were covered from the outset, $F(1, 47) = 7.32$, $p = .009$, $\eta_p^2 = .14$. Translating to Simon effect asymmetry, it was not found in PE with prior

in Experiment 2. The error bars reflect Cousineau-Morey confidence intervals (Morey, 2008)

hand visibility (left stimulus: 0.3% , $p = .668$, $BF_{10} = 0.23$; right stimulus: 0.9% , $p = .268$, $BF_{10} = 0.41$), with a reversed effect obtained without prior hand visibility (left stimulus: 1.4% , $p = .018$; right stimulus: -0.4% , $p = .587$, $BF_{10} = 0.25$).

No other effects were significant, with only the response location $\times$ prior visibility $\times$ experiment interaction, $F(1, 92) = 3.01$, $p = .086$, $\eta_p^2 = .03$, $BF_{10} = 0.60$, and stimulus location $\times$ response location $\times$ prior visibility $\times$ experiment interaction, $F(1, 92) = 3.29$, $p = .073$, $\eta_p^2 = .03$, $BF_{10} = 2.11$, showing F ratios greater than 1.0.

Discussion

The Simon effect asymmetry for RT was evident both when participants saw the apparatus and hand placement prior to their being covered up and when they did not. Note that the 0-ms Simon effect for the left stimulus location does not indicate a lack of influence of stimulus-response correspondence

because the speed advantage for right responses works counter to any advantage for location correspondence in that case. That the Simon effect asymmetry for RT was evident when the apparatus and participants' hands on it were covered up from the beginning is in contrast to the results reported by Wallace (1972). We consider this issue in detail in the *General discussion*, after presenting the results of a similar study conducted with foot-press responses.

Neither RT nor PE differed significantly across the two visibility conditions, indicating that overall performance was similar in the two conditions. Also, the Simon effect asymmetry in the RT data did not differ significantly for the two visibility conditions, as indicated by the lack of interaction between response location and prior visibility. However, the PE data did show such an interaction, indicating different patterns for the two visibility conditions. With prior visibility, the advantage for the right response in the RT data was paired with no significant difference in the PE data. Without prior visibility, there was an interaction for PE such that false-left responses were more frequent than false-right responses, which discounted the possibility that there was a bias toward responding "right." BIS analyses showed that the right response still had an advantage when the nonsignificant error difference was taken into account for the condition with prior visibility, $F(1, 47) = 6.18$, $p = .017$, $\eta_p^2 = .12$, whereas the opposing speed and accuracy patterns for the condition without prior visibility eliminated the response-location effect, or the Simon effect asymmetry, $F(1, 47) < 1.0$, $BF_{10} = 0.18$. We interpret these results as suggesting that the Simon effect asymmetry for RT could reflect at least in part a bias to respond "right" with prior visibility but not without prior visibility.

Experiment 3: Visibility of response pedals and foot placement

Foot responses yielded a Simon effect asymmetry for RT like that for the hand responses in Experiment 1. Experiment 2 found that the asymmetry for hand responses was evident even when the response apparatus and hands on them were not visible from the beginning. That result implies that a visual representation is not necessary to produce the asymmetry. If that is indeed the case, then blocking visibility of the pedals and feet from the beginning should similarly not eliminate the Simon effect asymmetry. Consequently, Experiment 3 examined this implication. All participants in Experiment 3 performed with pedal-press responses using the feet. One group was not allowed to see their feet on the pedals throughout the experiment. The other group had full view of their feet on the apparatus throughout the experiment. This latter condition was different from the comparison group in Experiment 2, for which the response situation was visible only prior to the

start of data collection, due to an intercontinental miscommunication. However, if participants who never see the apparatus or their feet on it show the Simon effect asymmetry, as do participants who can see them the whole time, then there is no reason to think that visibility prior to the apparatus and feet being covered would produce any different result.

Method

Participants Fifty-two students (39 female, 13 male) from RWTH Aachen University took part in the experiment for partial course credit. Handedness and footedness were measured as in Experiment 1, and six participants who were left-handed, ambidextrous, or had a negative footedness score were excluded. Participants were randomly assigned to two experimental groups. Participants in one group were not allowed to see their feet (i.e., the with visibility group) during the experiment and those in the other group were allowed to see their feet (i.e., the without visibility group); the latter group had two participants more than the former. We therefore excluded randomly two participants of the with visibility group to make the group sizes equal. Significance levels in the results were not influenced by excluding these two participants.

The with-visibility group had a mean handedness score of 84.5 ($SD = 17.7$) and a mean footedness score of 9.6 ($SD = 3.9$). It was composed of 18 females and four males and the mean age was 23.2 years ($SD = 4.1$). The without-visibility group had a mean handedness score of 86.9 ($SD = 19.5$) and a mean footedness score of 11.7 ($SD = 4.4$). It was composed of 16 females and 6 males with a mean age of 22.7 years ($SD = 3.4$).

Apparatus, stimuli, tasks, and procedure The setup was exactly like that of Experiment 1, except that participants responded with the foot-pedal responses throughout the experiment and the installment of a black cloth for the without-visibility group. The participants in that group were not allowed to see the foot-pedals and had their feet positioned on the foot pedals by the experimenter. Their legs, feet, and foot-pedals were covered by a black cloth throughout the whole experiment. The black cloth was not used for the with-visibility group.

Design The independent variables were stimulus location (left vs. right; within-participants), response location (left vs. right; within-participants), and foot visibility (with vs. without; between-participants). The dependent variables were RT and PE.

Results

We again filtered trials with RT above 900 ms and below 100 ms (4.1%), as well as error trials (3.9% of all trials) for

the analysis of the RT. For RT, foot visibility elicited a main effect, $F(1, 42) = 4.17$, $p = .048$, $\eta_p^2 = .09$. The without-visibility group responded 33 ms faster than the with-visibility group ($M_s = 478$ ms vs. 511 ms). There was also a small main effect of stimulus location, $F(1, 42) = 4.29$, $p = .044$, $\eta_p^2 = .09$, with right stimulus being responded to faster than left stimulus ($M_s = 492$ ms vs. 496 ms). Foot visibility did not interact with stimulus location, $F < 1$, $BF_{10} = 0.21$.

Stimulus location and response location interacted, indicating the Simon effect, $F(1, 42) = 121.68$, $p < .001$, $\eta_p^2 = .74$. The Simon effect did not interact with foot visibility, $F < 1$, $BF_{10} = 0.38$. Like in the prior experiments, response location elicited a main effect, $F(1, 42) = 35.19$, $p < .001$, $\eta_p^2 = .46$, as responses were 25 ms faster with the right foot than with the left foot ($M_s = 482$ ms vs. 507 ms). This result, as expected, is indicative of the Simon effect asymmetry (see Fig. 3), with a larger Simon effect for right ($M = 60$ ms, $p < .001$) than for left stimuli ($M = 10$ ms, $p = .086$, $BF_{10} = 0.82$). Moreover, foot visibility did not interact with response location, $F(1, 42) = 1.43$, $p = .239$, $\eta_p^2 = .03$, $BF_{10} = 0.55$, indicating that the

Simon effect asymmetry was not modulated significantly by foot visibility.

For PE, foot visibility elicited a nonsignificant tendency for a main effect, $F(1, 42) = 3.81$, $p = .058$, $\eta_p^2 = .08$, $BF_{10} = 1.32$. In the without-visibility group, 2.1% more errors were made than in the with-visibility group, countering the shorter RT for the former group than for the latter. The only significant effect was the Simon effect. Stimulus location and response location interacted, $F(1, 42) = 4.37$, $p = .043$, $\eta_p^2 = .09$. The Simon effect for PE was 0.5% ($p = .733$, $BF_{10} = 0.38$) for left stimuli and 1.3% ($p = .459$, $BF_{10} = 0.89$) for right stimuli (see Fig. 3). For all other effects, $F_s < 1$, $BF_{10}s < 0.37$.

Discussion

The results showed that foot visibility did not influence either the Simon effect for RT or its asymmetry significantly. The asymmetry was evident both with the feet visible and with them not being visible. This result for foot responses is in agreement with that for hand responses. Note that the two

Fig. 3 Mean reaction times (RTs) and percentage errors (PEs) depicted as a function of stimulus location (left vs. right), response location (left vs. right) and group (with foot visibility vs. without foot visibility) in

Experiment 3. The error-bars reflect Cousineau-Morey confidence intervals (Morey, 2008)

groups in Experiment 3 differed in whether or not they could see their feet on the pedals *throughout* the experiment. If there were any substantial effect of occluding the feet and pedals, it should have been evident in these results, for which the visual conditions are the most distinct. It is thus reasonable to infer that being able to see the pedals and/or feet does not contribute much, if any, to the Simon effect asymmetry with foot responses.

Because RT was longer but PE was less when the feet were visible than when they were not, the overall RT difference can be attributed to a speed-accuracy tradeoff. This was reflected in an analysis of BIS that showed no main effect of foot visibility, $F(1, 42) < 1.0$, $BF_{10} = 0.28$. Because neither RT nor PE showed an interaction of response with visibility condition, the comparison for BIS of responses collapsed across visibility conditions is most relevant. That comparison showed a significant asymmetry favoring the right response, $F(1, 42) = 8.45$, $p = .006$, $\eta_p^2 = .17$. This outcome is similar to that for the foot responses in Experiment 1 in showing that the Simon effect asymmetry in RT may be due in part to a bias to respond with the right foot.

General discussion

The present study examined whether right-footed persons show a Simon effect asymmetry when responding with the feet similar to that shown by right-handed persons when responding with the hands. We also examined whether the Simon effect asymmetry for either effector set relies on visibility of response effectors and devices, which comparison of Seibold et al.'s (2016) and Wallace's (1972) studies suggested might be the case. The pattern of asymmetric Simon effects in RT with a bias towards the right effector's side was found for both keypress responses made with the hands and pedal-press responses made with the feet. These results are in agreement with prior studies using hand responses (Rubichi & Nicoletti, 2006; Seibold et al., 2016; Spironelli et al., 2009; Tagliabue et al., 2007), and we are not aware of any prior study that has examined the Simon effect asymmetry for responses made with the feet. The finding that the feet show an asymmetry similar to that for the hands is in accord with the view that the Simon effect asymmetry in RT is mainly an artifact of faster responses with the dominant hand than with the subordinate one (Seibold et al., 2016).

These asymmetric patterns were evident through the main effect of response location. Because the current participants were right-handed and right-footed, they responded faster with their right effectors. The Simon effect in RT equals the RT on non-corresponding trials minus the RT on the corresponding trials. For the left-side stimuli, the non-corresponding responses were made with the faster right effector and the corresponding responses with the slower left

effectors. This relation was reversed for right-side stimuli. As a result, the Simon effect was smaller for the left-side stimuli than for the right-side stimuli, due to this difference in RT for the left and right effectors. This explanation of the Simon effect asymmetry is consistent with the dominant-hand advantage found in the Simon effect literature (Proctor & Wang, 1997; Rubichi & Nicoletti, 2006; Seibold et al., 2016; Simon, Sly, & Vilapakkam, 1981; Spironelli et al., 2009; Tagliabue et al., 2007).

Spironelli, Tagliabue, and Angrilli (2006) conducted an experiment similar to the present ones with 10 right-handed participants for which they measured hemispheric asymmetries in event-related potentials (ERPs), in addition to RT. Their RT data showed a Simon effect asymmetry similar to those in our experiments: The right response was 11 ms faster than the left response, yielding a larger Simon effect for the right stimulus location (37 ms) than for the left stimulus location (15 ms). The ERP data showed an interaction of spatial correspondence with stimulus location, indicative of the Simon effect asymmetry. Recollect that when stimulus location and response location are separated in the analysis, this term is the response location main effect. The ERP results also showed significant left cortical activation to stimuli presented in the right visual field during a window of 140–160 ms after stimulus onset, whereas left stimuli showed significant activation of the right versus left hemisphere in the next 160- to 180-ms window. Spironelli et al. related the earlier cortical activation for right stimuli to the Simon effect asymmetry. Although stimulus location showed lateralization differences for the early phase of processing within 200 ms of stimulus onset, neither the correspondence variable (Simon effect) nor correspondence $\times$ stimulus location term (Simon effect asymmetry) interacted with lateralization. The stimulus location $\times$ correspondence $\times$ lateralization interaction was significant only in a separate analysis of the later phase of 200–400 ms, the period during which participants would be selecting responses. Thus, although right-handers may show earlier activation for the right stimuli, no direct impact on the Simon effect was evident in Spironelli et al.'s data.

Although we did not test left-footed participants in the current study, a similar Simon effect asymmetry showing a larger Simon effect for the dominant left effector should be evident for left-footed participants. For left-footed participants, it is expected that they will respond faster with the left, dominant foot than the right foot. Thus, a larger Simon effect is expected for left responses than for right responses for the left-footed participants in a similar way to that for the right-footed participants who show the larger Simon effect for right responses.

Moreover, our Experiment 2 showed that the Simon effect asymmetry in RT was apparent regardless of whether the hands and response-keys were visible prior to the experiment. In addition to Seibold et al.'s (2016) Experiment 2, which showed that seeing responding hands and response keys

during the experiment did not affect the Simon effect asymmetry, this new experiment indicates that the visual sensory input for the response hands and keys prior to their being covered up is not critical for the Simon effect asymmetry. This pattern was also true for foot-press responses in our Experiment 3, for which occluding participants' feet and pedals did not significantly reduce the Simon effect asymmetry. These results from both the hand- and foot-responses provide evidence that the Simon effect asymmetry is not due to a visual matching of the stimulus locations and response locations that requires visibility of the response effectors and devices, either as the task is performed or in advance.

Our findings of the Simon effect in conditions both with and without effector visibility are in agreement with Wallace's (1972) claim that the spatial stimulus-response compatibility can occur without visual coding of the response locations. The Simon effect asymmetry found for both hand- and foot-responses regardless of visibility of the response effector and device, though, is inconsistent with Wallace's results. Wallace found the Simon effect asymmetry when the hands and response keys were visible to the participants, but not when the participants were prevented from seeing their hands and the response keys. There are several possible reasons why Wallace's results may have differed from ours. The first is that he tested only six participants under these conditions in his Experiment 1 and four in Experiment 2. Thus, his study had lower power for detecting an asymmetry. Second, each participant in Wallace's "no hands" condition wore a halter that did not allow them to see "any part of his upper limbs or the response keys" (p. 164). This is slightly different from our Experiment 2 setup, in which participants were not able to see their hands and response keys, but their upper arms were not covered.

Third, Wallace's (1972) experiments included trials for which the stimuli could occur above or below the fixation point intermixed with those in which the stimuli occurred left or right of fixation. The inclusion of stimuli located on the vertical dimension would change the nature of the task, and we have found that the RT advantage for right-hand responses does not occur in some task contexts (Seibold et al., 2016, Experiment 1). Thus, there is a slight possibility that presence of stimuli varying along the vertical dimension diluted the Simon effect asymmetry unless the responding hands were visible to reinforce the left-right distinction. Fourth, participants in Wallace's experiments made circle/square form judgments, whereas those in our experiments made red/green color judgments. There is not an obvious reason why the difference in the required judgment would matter, although Zhong, Proctor, Xiong, and Vu (2020) found apparent differences for form and color judgments in variations of the Simon task for vertically oriented stimulus and response displays. Regardless of why our results differed

from those of Wallace, they show unambiguously that the Simon effect asymmetry for right-handed persons, due to the faster response with the dominant limb, can be obtained in conditions for which participants do not see the response device or their limbs placed on it.

Although foot responses showed a similar Simon-effect asymmetry to hand responses in the RT data, distinct patterns of results when incorporating PE were evident for the two effector sets. Two out of the three conditions for which the responses were made with the hands, the PE data did not show more false-right than false-left responses, which resulted in the BIS analysis showing no bias to make the right response. Prior studies of the Simon effect asymmetry likewise showed little evidence of a tendency for false-right responses to predominate (Rubichi & Nicoletti, 2006; Seibold et al., 2016; Tagliabue et al., 2007). In the present study, only the prior visibility condition showed a significant response location effect in the PE analysis, but there is no reason to think that prior visibility should differ from the condition with complete visibility if the condition without prior visibility did not. The minimal role of bias for responding with the right hand thus suggests that the Simon effect asymmetry for RT arises primarily from faster response execution of the right hand, after the right response is selected.

In contrast, all three conditions with foot responses showed, at least numerically, false-right errors to outnumber false-left errors, implying an overall bias for right foot presses, as confirmed by the BIS analyses. It is possible that, for the feet, the Simon effect asymmetry for RT is entirely due to a bias to respond with the right foot. However, we think it more likely that this asymmetry for foot responses, which tended to be larger in RT across the experiments for the feet compared (> 40 ms) to the hands (15 ms), has contributions of both a response-selection bias and a response execution advantage. Exactly why foot responses showed a bias that the hand responses did not cannot be determined, but one possibility is that it is a consequence of the foot pedals requiring more force to operate than the buttons on the response box used for the hands.

In conclusion, the results from three experiments provide evidence that, for right-footed persons, foot dominance influences the Simon effect asymmetry for RT similarly to hand dominance, leading to a larger Simon effect for stimuli on the dominant right side than the nondominant left side. However, the asymmetry for foot responses seems to include a bias to respond with the right foot, which the asymmetry for hand responses does not. Moreover, the Simon effect asymmetry in RT can be obtained for both the hands and feet without visual sensory input for the response effectors and devices, indicating that the underlying mechanism of this asymmetry effect is not based on a visual representation of the response situation.

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Open practices statement The data for all experiments are available from the authors upon request.

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