The Simon effect of spatial words in eye movements: Comparison of vertical and horizontal effects and of eye and finger responses

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Abstract

Spatial stimulus location information impacts on saccades: Pro-saccades (saccades towards a stimulus location) are faster than anti-saccades (saccades away from the stimulus). This is true even when the spatial location is irrelevant for the choice of the correct response (Simon effect). The results are usually ascribed to spatial sensorimotor coupling. However, with finger responses Simon effects can be observed with irrelevant spatial word meaning, too. Here we tested whether a Simon effect of spatial word meaning in saccades could be observed for words with vertical (“above” or “below”) and horizontal (“left” or “right”) meanings. We asked our participants to make saccades towards one of the two saccade targets depending on the color of the centrally presented spatial word, while ignoring their spatial meaning (Experiment 1 and 2a). Results are compared to a condition in which finger responses instead of saccades were required (Experiment 2b). In addition to response latency we compared the time course of vertical and horizontal effects. We found the Simon effects due to irrelevant spatial meaning of the words in both saccades and finger responses. The time course investigations revealed different patterns for vertical and horizontal effects in saccades, indicating that distinct processes may be involved in the two types of Simon effects.

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1. Introduction

Stimulus location affects saccade efficiency. Saccades towards a target stimulus (so-called pro-saccades) are faster and more accurate than saccades away from a target stimulus (so-called anti-saccades; Everling & Fischer, 1998; Hallett, 1978). In this respect, saccades are similar to other spatially directed movements, such as manual responses. Like saccades, manual responses are facilitated in spatially stimulus–response (S–R) compatible as compared to spatially S–R incompatible conditions: For example, responding to a stimulus on the left with a left-hand button press is faster than responding to a stimulus on the right with a left-hand button press (cf. Fitts & Seeger, 1953).

To note, spatial S–R compatibility levels affect manual responses even when stimulus location is task-irrelevant (Simon, 1990; Simon & Rudell, 1967). This is the Simon effect. For example, when the participants respond with the right index finger to a green stimulus and with the left index finger to a red stimulus, stimulus location is irrelevant for the choice of the correct responses. Yet, in this situation, responses are faster for compatible stimuli (e.g., green targets on the right and red targets on the left) than for incompatible stimuli (e.g., green targets on the left and red on the right). The Simon effect might depend on additional side conditions, such as the particular kind of spatial information that is used for the discrimination between the responses (cf. Ansorge & Wühr, 2004), the speed of the responses (cf. Proctor, Miles, & Baroni, 2011), or the type of stimulus that is used (cf. Pellicano, Lugli, Baroni & Nicoletti, 2009). Besides these limitations, however, the Simon effect is very robust (Hommel, 2011). A Simon effect can even be produced by the influence of irrelevant spatial word meaning on button presses (e.g., Proctor & Vu, 2002).

1.1. Explanation of the Simon effect

According to the most widely accepted explanation of the Simon effect, the dual-route model, response selection can occur along two ways – direct and indirect routes (Kornblum, Hashbrouq, & Osman, 1990; Zhang, Zhang, & Kornblum, 1999). Along the indirect route, the participants translate the relevant target features (e.g., colors) into the required responses (e.g., button presses). This processing is top-down controlled: The participants carry out these processes according to the instructions. At the same time, along the direct route spatial information conveyed by target position can automatically facilitate selection of a spatially compatible
response. According to the dual-route model, response selection is facilitated in the spatially compatible conditions because selection along the direct and along the indirect routes converges on the selection of the same required response. By contrast, in the incompatible conditions, there is conflict between the direct and indirect route delaying the selection of the correct response (Kornblum, Hashbrouc, & Osman, 1990; Zhang, Zhang, & Kornblum, 1999).

1.2. Purpose of the present study

In the current study, we tested whether such a Simon effect can also be found with saccades (instead of manual responses) in the visual modality with response-irrelevant spatial meaning of visually presented words. Previous research demonstrated an auditory Simon effect on saccades, with high- vs. low-pitched tones presented either to the left or right side of the central fixation (Bertera et al., 1975; Leuthold & Schröter, 2006). So far, however, it is unclear whether the same effect could be found with saccades made in response to visual words with a spatial meaning, too. To be sure, a Simon effect based on irrelevant spatial word meaning can be found with manual keypress responses (Ansorge et al., 2010; Pellicano et al., 2009). Responding with the left finger to the word ‘left’ is faster than responding with the right finger to the same word, even if the spatial meaning of the word is irrelevant for the required response (e.g., Pellicano et al., 2009). However, it is more questionable whether such a Simon effect of spatial word meaning could also be found with saccades. Saccades are the fast eye movements by which the eye jumps from location to location, and they are frequently made during reading (Rayner, 1998). Yet, at the moment no standard reading model does incorporate the idea that irrelevant spatial word meaning could have an influence on saccade characteristics made after reading a word (Kliegl, Nuthmann, & Engbert, 2006; Reichle, Rayner, & Pollatsek, 2003; Reichle et al., 1998). On the basis of current reading models, it therefore appears unlikely that a Simon effect based on spatial word meaning on a subsequent saccade could be found.

Yet recent models of embodied cognition entail the possibility that word meaning could be grounded in more fundamental sensorimotor representations (Barsalou, 1999, 2008; Glenberg & Kaschak, 2002; Zwaan, Stanfield, & Yaxley, 2002). On the basis of these models of language comprehension, word meaning is understood by the reader by means of the elicitation of past sensorimotor experiences that the reader originally used to make sense of the words in the first place (Barsalou, 1999). One could therefore predict on the basis of the embodied cognition models of language comprehension, a sensorimotor effect, such as the Simon effect, in which a sensory (here: spatial) representation that is evoked by a word’s meaning influences the efficiency of a subsequent motor response, even when this motor response consists in a saccade.

In line with this possibility, Hodgson et al. (2009) found that participants initiated faster saccades when the irrelevant spatial meaning of a word (e.g., ‘left’) was compatible with the saccade direction (e.g., towards the left) than when the word had an incompatible meaning (e.g., if the word ‘left’ required a saccade to the right). In that study, the participants made an eye movement towards a saccade-target box in the periphery of a computer screen. On each trial, four differently colored saccade-target boxes were shown, one above, one below, one left, and one right of the screen center. Which of these boxes served as the actual trial’s saccade target was determined by the color of a centrally presented target word. For example, if a word, such as ‘right’ was presented in blue participants had to saccade to the blue saccade-target box, regardless of the word’s meaning. Therefore, word color was relevant for saccade selection and word meaning was irrelevant. Yet, saccades were facilitated by spatially compatible word meaning relative to spatially incompatible word meaning. For example, if a blue word required a saccade to the left, this response was facilitated if the word read ‘left’ than if it was ‘right’.

Yet, whether these Saccadic Reaction Time (SRT) effects of Hodgson et al. (2009) reflected a Simon effect — that is, a Stimulus–Response (S–R) compatibility effect between the location meaning of the words and the saccade directions, or whether the effect was due to a stimulus–stimulus (S–S) correspondence effect remains to be tested. An explanation of the SRT effect in terms of S–S correspondence is possible because spatial S–R compatibility and S–S correspondence were confounded. Remember that the central words were always of the same color as the saccade-target boxes. Thus, it is possible that the words created two types of sensory effects — one grouping effect of the similarly colored word and saccade-target box leading to a shifted relative screen location of the grouped color stimuli and one sensory effect of word meaning. These sensory effects were either S–S corresponding or S–S non-corresponding to one another. They were S–S corresponding if the color-grouped stimuli were on the same side that was indicated by the word’s irrelevant location meaning. In these conditions, the grouping-based location and word meaning jointly facilitated the selection of the same veridical saccade-target box. Grouping-based location and word meaning were S–S non-corresponding to one another if the word’s color grouped with a response box opposite to the word’s irrelevant location meaning. In that case grouping-based location and the word’s location meaning would have been in conflict with another. Although we think that the results of Hodgson et al. (2009) most likely reflected a Simon effect, the alternative possibility in terms of sensory effects that we discussed above needs to be ruled out.

2. Experiment 1

To clear matter, we took two measures. First, we ruled out S–S color grouping between the words and the saccade-target boxes. To this end, in each trial, we presented two saccade-target boxes in the same fixed (here: black) color, which was different from the possible target-word colors (here: green and turquoise). Under these conditions, S–S correspondence between grouped location and word meaning is impossible. However, sensory location priming of one saccade target by the irrelevant spatial word meaning would still be possible. For instance, the word ‘left’ could again facilitate processing a saccade target-box on the left. We therefore took a second measure. We studied the spatial compatibility effect as a function of the speed of the SRT. Prior research with manual responses and visual–spatial location code has shown that Simon effects based on horizontal code (i.e., left and right stimulus positions) decrease with an increasing RT, whereas Simon effects based on vertical code (i.e., stimulus positions above and below) remain stable or even increase with an increasing RT (Proctor, Vu, & Nicolletti, 2003; Stürmer et al., 2002; Wiegand & Wascher, 2005, 2007). Therefore, if spatial word meaning affects SRTs via Simon effects, we expected a similar pattern for saccades: Across the distribution of SRTs, we expected a decreasing compatibility effect with horizontal word meaning and a stable or even increasing compatibility effect with vertical word meaning.

To note, however, the different developments of vertical vs. horizontal Simon effects over time in previous studies were based on physical stimulus locations as an independent variable. Also, Wiegand and Wascher (2005) explained the quickly fading horizontal Simon effect with the automatic translation of horizontal stimulus code into corresponding motor activation via the dorsal stream of the cortical visual system, and they explained the vertical Simon effect’s increase over time with the more time-consuming cognitive translation of the vertical stimulus location code into a corresponding vertical response activation code within the ventral stream of
the cortical visual system. In addition, recent studies that investigated the time course of Simon effects based on irrelevant word meaning consistently showed an increasing Simon effects over time, even if horizontal word meaning and left–right manual responses were used (Miles & Proctor, 2009, 2012; Pellicano et al., 2009; Proctor et al., 2009; Vu & Proctor, 2011). On the basis of these findings, our expectations about different time-dependent developments of Simon effects for vertical vs. horizontal saccades might appear unjustified.

One should note, however, that although different from the brain structures responsible for manual responses, brain structures for the control of vertical vs. horizontal saccades are also not the same: While the horizontal aspect of saccades is brought about by motoneurons in the abducens nucleus in the pontomedullary brain stem, the vertical aspect is steered by motoneurons in the trochlear nucleus at the ventral border of the periaqueductal gray matter (Horn & Leigh, 2009). Second and related, reminiscent of the greater demands imposed by the translation of vertical stimulus code into vertical manual response code, vertical saccades are more vulnerable to progressive brain disease, such as chorea–acanthocytosis, than horizontal saccades (e.g., Gradstein et al., 2005). Such findings indicate that there is at least good reason to expect differences between Simon effects with vertical vs. horizontal saccades, although it is maybe less certain whether these differences are of exactly the same type as the differences between vertical and horizontal manual responses. Finally, from an embodied cognition perspective, it seems worthwhile to test whether (the typical) differences between vertical vs. horizontal Simon effects could not also be found with spatial word meaning when saccades are used instead of finger responses. From an ontogenetic perspective, it could well be that spatial meaning is at least partly grounded in the control of eye movements because the development of instrumental eye movements also starts early in childhood. Looking preferences for novel as compared to familiar objects based on a viewer’s past experience, for example, are found as early as after 4–8 weeks of age (e.g., Wattam-Bell, 1996). Thus, sensorimotor representations of eye movements could be grounding some forms of abstract spatial meaning, and saccades could accordingly provide a very sensitive test for different effects of vertical than horizontal word meaning.

We also varied the stimulus onset asynchrony (SOA) between the irrelevant spatial word meaning and the imperative signal of the target (here: the word’s color). To that end, the spatial words changed their colors at three levels of SOA: 0 ms, 100 ms, or 200 ms prior to the color change of the same word. This was done to foster the Simon effect in at least some of the conditions because Vu and Proctor (2001) have shown that irrelevant location words (or color words) produce their largest compatibility effects on keypress responses when presented prior to the relevant stimulus dimension (color or arrow direction in Vu & Proctor).

2.1. Method

2.1.1. Participants

Twenty-five students (20 female) with a mean age of 24.0 years participated in Experiment 1. Here and in the following experiment, all participants had normal or corrected to normal vision. Also, informed consent was obtained from the participants, and the participants were treated in accordance with the rules of the declaration of Helsinki. Participants received course credit for participation.

2.1.2. Apparatus

Visual stimuli were presented on a 19-in., color CRT monitor (Sony Multiscan G400), with a screen resolution of 1024 × 768 pixels, on a standard computer with a standard keyboard. The monitor’s refresh rate was 60 Hz. The participants sat at a distance of 57 cm from the screen in a quiet, dimly lit room, with their head resting on a chin rest to ensure a constant viewing distance and a straight-ahead gaze direction. Eye movements were recorded via the SR Research Ltd. Eye-Link 1000 eye tracker. Gaze position was sampled at a rate of 1000 Hz. After 9-point calibration at the outset of the experiment, gaze-position error was less than 0.5°. Binocular tracking was used, but only data from the eye that had smaller validation error was used for analyses.

2.1.3. Stimuli

All stimuli were presented on a gray background (CIE Lab coordinates: \( L^* = 76.18, a^* = -6.59, b^* = -4.58 \)). As target words, we presented German words with a spatial meaning, ‘oben’ (Engl. ‘above’), ‘unten’ (Engl. ‘below’), ‘links’ (Engl. ‘left’), and ‘rechts’ (Engl. ‘right’), all in lowercase, in either green (\( L^* = 66.12, a^* = -76.10, b^* = 61.07 \)) or turquoise color (\( L^* = 68.78, a^* = -45.92, b^* = -16.33 \)). The words were shown at the center of the screen. In addition two small black (\( L^* < 1.00, a^* = 0, b^* = 0 \)) squares, each 1.0° × 1.0° in size, were used as saccade-target boxes. The boxes were shown at an eccentricity of 5.0°, either above and below screen center (in the vertical blocks) or left and right of screen center (in the horizontal blocks).

2.1.4. Procedure

See Fig. 1 for examples of a sequence of events in a trial. After fixating the screen center, the participants started the next trial by pressing the space-bar on the keyboard with the index finger of their dominant hand. Next, a black central fixation cross and two peripheral saccade-target boxes were jointly presented for 400 ms. After this time, the fixation cross was turned off and a word was shown (in a font size of 20 points) at screen center. (The saccade-target boxes remained on the screen throughout the experiment.) In one third of the trials, the word was presented in black for 200 ms, and then changed its color into turquoise or green. This was the 200-ms SOA (stimulus onset asynchrony) condition. In another third of all trials, the SOA was 100 ms, and in the remaining trials, the word was presented immediately colored (in turquoise or green). In all cases, the colored target word remained on the screen for another 200 ms.

The task of the participants was to saccade towards one of the two saccade-target boxes depending on the color (green or turquoise) of the word. The word’s meaning varied independently of the word’s colors, so that no correlation between meaning and color existed. Participants were informed about this fact and instructed to best ignore the word meaning. However, due to the relatively difficult discrimination between blue and turquoise word colors, word meaning should have been available prior to color discrimination, even in conditions with a 0 ms SOA.

In the vertical block, the participants had to saccade upwards or downwards and the target words were the German words for ‘above’ and ‘below’, presented either in green or turquoise. Twelve of the participants made an upward saccade for turquoise words and a downward saccade for green words. This mapping was reversed with the remaining 13 of the participants. In the horizontal block, the participants had to saccade leftwards or rightwards to the green and turquoise German words for ‘left’ and ‘right’, again, with color-saccade-direction mappings approximately balanced across participants.

Because the irrelevant word meaning and the relevant word color were uncorrelated, half the words had an S–R compatible meaning and half of the words had an incompatible meaning. Compatible and incompatible trials, trials with words of different colors, and trials with different word-color SOAs were presented in a pseudo-randomly interleaved sequence, with the following
The experiment consisted of two blocks, one vertical and one horizontal block, and each block consisted of 64 trials per each of the compatible and incompatible conditions and each of the 3 SOAs (word-color SOAs of 200 ms, 100 ms, or 0 ms), leading in total to 384 trials per block, plus 10 training trials in the beginning. The whole experiment thus consisted of 768 trials, plus 20 training trials, 788 trials in total. The sequence of the blocks (horizontal block first; vertical block first) was balanced across participants. The experiment was run in a single session and the whole experiment took about 1 h.

2.2. Results

Saccadic Reaction Times (SRTs) were measured in milliseconds from word (not color) onset to saccade onset. This was done in order to look at the distribution of SRTs from the onset of the word. However, additional analyses in which the SRTs were measured from the onset of word color are also reported below. Trials in which the word was initially not fixated or in which no saccade was made towards either of the two saccade-target boxes were discarded (4.9%).

2.2.1. SRTs

Mean correct SRTs for each participant and condition were calculated. Trials with SRTs faster or slower than 2 standard deviations from the individual mean correct SRTs were discarded (3.4%). The resulting mean correct SRTs are depicted in Fig. 2 (upper panel). As can be seen, we found a Simon effect, regardless of SOA. This was confirmed by formal analysis.

An omnibus repeated-measures ANOVA, with the within-participant variables axis (vertical vs. horizontal block), SOA (0 ms, 100 ms, or 200 ms), and compatibility (compatible vs. incompatible) led to the following results. The main effect of compatibility was significant, $F(1, 24) = 14.05$, $p < .01$, partial $\eta^2 = .37$. Performance was faster in the compatible condition ($M = 488$ ms) than in the incompatible condition ($M = 495$ ms). Additionally, we found a significant effect of SOA, $F(2, 48) = 1391.06$, $p < .001$, partial $\eta^2 = .98$. Saccades were faster with an SOA of 0 ms ($M = 397$ ms), and SRTs were delayed with an SOA of 100 ms ($M = 579$ ms), all $t$s(24) $> 25.00$, all $p$s < .01 (Bonferroni corrected). In addition, there was a two-way interaction of SOA and axis, $F(2, 48) = 5.12$, $p < .03$, partial $\eta^2 = .18$. Mean SRTs between different axes differed most at an SOA of 0 ms [vertical: $M = 413$ ms vs. horizontal: $M = 382$, $t(24) = 1.49$, $p > .14$] and less at 100 ms (vertical: $M = 504$ ms vs. horizontal: $M = 492$, $t < 1.00$), and at 200 ms (vertical: $M = 587$ ms vs. horizontal: $M = 592$, $t < 1.00$). No other significant effect or interaction was found, all $Fs < 1.00$.

The same ANOVA of the SRTs as measured from the color onset showed the same results as above, except that as would be expected, the main effect of SOA changed, $F(2, 48) = 18.60$, $p < .001$, partial $\eta^2 = .44$, reflecting a decrease in mean SRTs (by about 100 ms and 200 ms, respectively) in the cases of word-color SOAs.
of 100 ms and 200 ms, respectively, and as compared to the 0-ms SOA condition.

2.2.2. SERs

The same omnibus ANOVA was also run on Saccadic Error Rates (SERs). The saccadic errors were the saccades that were made to the opposite side of the currently pertaining saccade-target box. The main effect of compatibility was again significant, \( F(1, 24) = 84.21, p < .001 \), partial \( \eta^2 = .79 \). Performance was more accurate in the compatible condition \( (M = 7.2\%) \) than in the incompatible condition \( (M = 12.0\%) \). We also found a significant effect of axis, \( F(1, 24) = 19.75, p < .001 \), partial \( \eta^2 = .45 \). Participants made fewer errors in the horizontal condition \( (M = 7.8\%) \) than in the vertical condition \( (M = 11.4\%) \). Also, we found a significant effect of SOA, \( F(2, 48) = 3.55, p < .04 \), partial \( \eta^2 = .13 \). The error rates were smaller when the SOA was 0 ms \( (M = 8.8\%) \) than when it was 100 ms \( (M = 10.4\%) \) or 200 ms \( (M = 9.7\%) \). No other significant effect or interaction was found, all \( F_s < 1.00 \). The mean SERs in each condition can be found in Fig. 2 (lower panel).

2.2.3. SRTs distribution analysis

Next, we studied how the compatibility effect varied with the speed of SRTs. To understand this, we sorted each individual’s correct SRTs, separately for each condition, from fastest to slowest. We then split each of these condition-specific SRT distributions into hexiles and calculated the mean SRT for each of the hexiles. As can be seen from Fig. 3, when we plotted the mean SRTs in compatible vs. incompatible conditions and as function of the block (or axis), SOA, and of the speed of SRTs, the compatibility effect varied differently across SRTs in the vertical (upper panel) than in the horizontal (lower panel) conditions: In the horizontal block, the compatibility effect decreased with an increasing SRT, while in the vertical block, the compatibility effect was more sustained across the SRT distribution.

Formally, this impression was corroborated by an analysis including the additional variable percentile of the SRT distribution (hexiles 1–6). In addition to the above mentioned significant effects, and the significant effect of percentile, here we also found a significant three-way interaction of percentile, axis, and compatibility, \( F(5,120) = 2.58, p < .04 \), partial \( \eta^2 = .10 \). As can be seen in Fig. 3, in the case of vertical responses, the compatibility effect (incompatible SRT – compatible SRT) increased with SRT latency [percentiles 2–6: all significant compatibility effects, \( t(s(24)) > 2.30 \), all \( ps < .05 \); percentile 1: \( t < 1.00 \)]. However, an opposite trend was observed in the horizontal block [percentiles 2–4: all significant compatibility effects, \( t(s(24)) > 2.30 \), all \( ps < .05 \); percentiles 1, 5 and 5: all non-significant compatibility effects, \( t(s(24)) < 2.10 \), all \( ps > .05 \)]. Further, we found a significant three-way interaction of percentile, axis, and SOA, \( F(10,240) = 3.98, p < .01 \), partial \( \eta^2 = .14 \). Among the faster SRTs, there was a clear-cut advantage for the SRTs in the horizontal as compared to the vertical blocks, 1st and 2nd percentile [vertical SRT minus horizontal SRT, all differences > 71 ms, all \( t(s(24)) > 5.00 \), all \( ps < .01 \)]. Only with an SOA of 0 ms, this horizontal-block advantage was also found in the 3rd hexile [SOA 0 ms: differences > 48 ms, \( t(s(24)) = 2.57, p < .05 \); SOAs 100 and 200 ms: differences < 35 ms, both \( ts < 2.00 \), both \( ps > .07 \)]. There were no such axis effects in the 4th and 5th hexile [differences < 51 ms, all \( t(s(24)) < 1.80 \), all \( ps > .09 \)], and finally, among the slowest SRTs, the effect clearly reversed showing an advantage of the vertical over the horizontal axis [differences of ~80 ms to ~131 ms, all \( t(s(24)) > 2.20 \), all \( ps < .05 \)]. In addition, we found a significant two-way interaction of percentile and axis, \( F(5,120) = 56.85, p < .001 \), partial \( \eta^2 = .70 \), and also a significant two-way interaction of percentile and SOA, \( F(10,240) = 10.05, p < .001 \), partial \( \eta^2 = .30 \). As explained, these were qualified by two significant three-way interactions. We did not find any other significant effect or interaction, all \( F_s < 1.00 \).

2.3. Discussion

The results provided evidence for a word-based Simon effect in SRTs (Vu & Proctor, 2001). Participants’ saccades were faster and more accurate if the word’s spatial meaning was compatible than if it was incompatible to the saccade direction. This was the case, although color grouping between the words and the saccade-target boxes was ruled out as a factor. The effect was even stronger in the error rates. This may be due to the swift onset of the saccades that was earlier than that of the typical manual keypress responses (compare to Experiment 2b, below). The faster responses meant that speed might have been traded for accuracy in the saccades, with the consequence that Simon effects would more likely show up (partly) in the ERs, too.

In line with the interpretation of the compatibility effect as a Simon effect, the compatibility effect also increased with SRTs in the vertical condition while it decreased with SRTs in the horizontal condition. A similar pattern of results has been found with Simon effects based on irrelevant visuo-spatial code and manual responses (Wiegand & Wascher, 2005, 2007; Wühr & Biebl, 2011) but not with manual responses to words (e.g., Pellicano et al., 2009). As explained, the differences between the present results and previous findings might be due to the use of saccades instead of manual responses in the present study. As with the human control of vertical vs. horizontal manual responses that Wiegand and Wascher (2005) believe to reflect motor control via the ventral
and the dorsal stream of visual cortical processing, respectively, the human control of vertical saccades is also of a different neuronal origin than the control of horizontal saccades. However, because the different neuronal substrates for the control of vertical vs. horizontal saccades reside in different parts of sub-cortical structures (cf. Horn & Leigh, 2009; Posner, Cohen, & Rafal, 1982), it is clear that the effects of spatial word meaning on saccades could have reflected a different and maybe even more fundamental aspect of embodied semantics than could be found with manual responses.

There was also an advantage for horizontal as compared to vertical conditions. This result again suggests that the compatibility effect could have reflected a Simon effect because this advantage of horizontal axis responses resembles a left–right prevalence effect that is typical of spatial compatibility effects (cf. Nicoletti & Umiltà, 1984) although not all findings suggest that the left–right prevalence effect is also found in Simon tasks, too (for a review, refer to Rubichi et al., 2006). However, the interaction of axis, SOA, and percentile suggested that this pattern was more typical for the faster responses.

In addition to these main results, SOA led to a trivial main effect. This SOA effect reflected that the color of the target began the later, the longer the SOA. In fact, the SOA effect on SRTs was almost identical to the length of the SOA. Also, SOA did not affect the size of the Simon effect but SOA interacted significantly with axis. Only with an SOA of 0 ms, we found a trend towards facilitation of vertical saccades as compared to horizontal saccades.

3. Experiment 2

Against the background of Experiment 1, Experiment 2 had two major aims. First, we wanted to replicate the findings of Experiment 1 with SRTs under slightly more conservative conditions and with a more fine-grained view of the development of the compatibility effect over the SRT distribution. We only included the shortest SOA of 0 ms, and used black and white targets. In Experiment 1, the smallest SOA of 0 ms between word onset and color onset has turned out to be sufficient for the compatibility effect of the irrelevant word meaning. Now we went one step further and used an even stronger color difference (between black and white) for the targets of the differently directed saccades. This should further decrease the effective color-word interval by allowing faster color discrimination in a horse race between color discrimination’s and word semantics’ influences on response selection. Also, to get a more fine-grained view of the development of the compatibility effect in vertical vs. horizontal blocks, we included more trials so that deciles rather than hexiles of the SRT distribution could be investigated. Second, we wanted to see whether the same or different results would be found with manual responses. Past research with manual responses has demonstrated that irrelevant left–right word meaning leads to an increasing compatibility effect with increasing manual RT (cf. Pellicano et al., 2009). We therefore wanted to test whether the required re-

3.1. Method

3.1.1. Participants

Fifteen students (10 female) with a mean age of 22.5 years participated in Experiment 2a, and 17 students (11 female) with a mean age of 23.0 years participated in a control condition with button presses (Experiment 2b).

3.1.2. Apparatus, stimuli, and procedure

These were similar to Experiment 1, except that only the SOA of 0 ms was used and the fixation cross and saccade targets were presented in blue whereas the target words were shown in black (luminance < 0.1 cd/m²) or white (luminance = 219.1 cd/m²) color. All stimuli were presented against the same gray background as it was used in Experiment 1. Participants made eye movements to the left or right in the horizontal block or upwards or downwards in the vertical block conditional on whether a word was shown in black or white.

Each vertical and horizontal block consisted of 130 trials per each of the two compatible and incompatible conditions, plus 10 training trials in the beginning, in sum the whole experiment consisted of 540 trials and took around 1 h.

3.1.3. Procedure of Experiment 2b

This was similar to Experiment 2a, except for the task of the participants. In Experiment 2b the task was to press a button depending on the contrast (black or white) of the target word, while ignoring the words’ spatial meaning. Finger responses were recorded via four number keys of the numeric keypad of a standard keyboard. The participants started each trial by pressing key #5 (i.e., the central key) of the number block. In the vertical block, the response keys were located above (key #8) and below (key #2) the starting key. In the horizontal block, they were right (key #6) and left (key #4) of the starting key. The participants used the index finger of their dominant hand for their key presses. They were instructed to keep the starting key #5 pressed until the target was shown, and then to press the response key depending on the color of the target. Number of trials and duration of were the same as in Experiment 2a.

3.2. Results

3.2.1. Experiment 2a (Saccades)

As in Experiment 1, the trials in which the target word was not fixated, no saccade was made towards either of the two boxes, or in which the SRT deviated by more than 2 SDs of the individual mean SRT of the respective condition were discarded (4.5%).

3.2.1.1. SRTs. The main effect of compatibility was significant, F(1,14) = 4.84, p < .05, partial η² = .26. SRT was faster in the compatible condition (M = 313 ms) than in the incompatible condition (M = 317 ms). Also the main effect of axis was significant, F(1,14) = 6.46, p < .03, partial η² = .32. Again, SRTs were faster in the horizontal condition (M = 308 ms) than in the vertical condition (M = 322 ms). The two-way interaction of axis and compatibility was not significant, F5 < 1.00 (but see below).

3.2.1.2. Saccadic error rates. The same omnibus ANOVA was run on saccadic error rates. The main effect of compatibility was significant, F(1,14) = 16.44, p < .01, partial η² = .54. Saccadic error rate was lower in the compatible condition (M = 4.3%) than in the incompatible condition (M = 9.3%). No other significant effect or interaction was found, all Fs < 1.00.

3.2.1.3. SRTs distribution analysis. As can be seen from Fig. 4, SRTs and saccadic compatibility effects varied differently in the vertical (circular symbols) and horizontal (triangular symbols) block. Formally, this assumption was corroborated by an omnibus ANOVA as described above but with the additional variable decile (or bin) of the SRT distribution (1–10). Besides the above mentioned significant effects of compatibility and axis, and a trivial main
effect of decile, we also found a significant three-way interaction of
decile, axis, and compatibility, \( F(9,126) = 4.32, p < .03, \) partial
\( \eta^2 = .24. \) As can be seen in Fig. 4’s lower panel, again with the verti-
cally directed saccades, the compatibility effect increased with
the response latency. In fact, the vertical compatibility effect
(incompatible RT/compatible RT) could only be found in the
6th (6 ms), 7th (8 ms), 8th (10 ms), and 10th (28 ms) decile, all sig-
nificant \( ts(14) > 1.80, \) all \( ps < .05 \) (one-sided). We did not find any
other significant effect or interaction, all \( Fs < 1.00. \)

3.2.2. Experiment 2b

3.2.2.1. RTs. RTs were measured from the target word onset until a
response key was pressed and, thus, included the movement times.
In addition, this experiment was run under the same conditions as
Experiment 2a – that is, the eye-tracker was used. Therefore the mean
RTs in this experiment were probably larger than in standard
keypressing experiments of the word-based Simon effect. For our
first analysis, only correct manual RTs were considered. As in
Experiment 1 and 2a, mean RTs for each participant and condition
were calculated, and trials that were faster or slower than 2 stan-
dard deviations of the individual mean were discarded (2.5%).

Correct mean RTs are depicted in Fig. 5 (upper panel). As can be
seen in Fig. 5, we found a compatibility effect. This was again con-
firmed by an ANOVA with the within-participant variables axis
(vertical vs. horizontal) and compatibility (compatible vs.
incompatible).

The main effect of compatibility was significant, \( F(1,16) = 15.25,
\( p < .001, \) partial \( \eta^2 = .49. \) Performance was faster in the compatible
condition \( (M = 742 \text{ ms}) \) than in the incompatible condition
\( (M = 767 \text{ ms}) \). We also found a significant effect of the variable axis,
\( F(1,16) = 23.80, p < .001, \) partial \( \eta^2 = .60. \) Performance was faster in
the horizontal condition \( (M = 722 \text{ ms}) \) than in the vertical condi-
tion \( (M = 787 \text{ ms}) \). The two-way interaction of the variables was
not significant, \( F < 1.00. \)

3.2.2.2. Error rates. The same omnibus ANOVA was also run on error
rates. The main effect of compatibility was again significant,
\( F(1,16) = 12.89, p < .01, \) partial \( \eta^2 = .47. \) Performance was more
accurate in the compatible condition \( (M = 0.4\%) \) than in the
incompatible condition \( (M = 2.3\%) \). No other significant effect or
interaction was found, all \( Fs < 1.00. \) The mean error rates are de-
icted in Fig. 5 (lower panel).

3.2.2.3. RT distribution analysis. We tested how the compatibility
effect varied with the speed of the responses. As can be seen from
Fig. 6, if plotted as a function of the speed of the responses, the
compatibility effect varied in a similar way in vertical (circular
symbols) and partly in horizontal (triangular symbols) conditions.
Formally this was supported by an omnibus ANOVA as described
above but with the additional variable decile (or bin) of the RT dis-
tribution \( (1–10) \). Besides the above mentioned significant effects
and a trivial significant effect of decile, we also found a significant
two-way interaction of decile and compatibility, \( F(9,144) = 6.34,
\( p < .02, \) partial \( \eta^2 = .28. \) As can be seen in Fig. 6, the compatibility
effect increased from 5 ms in the 1st decile to 45 ms in the 10th
decile and it was significant in all but the first decile, all significant
\( ts(16) > 2.40, \) all \( ps < .05 \). Thus, as previously found with manual re-
ponses, the compatibility effect of word meaning increased with
response latency also for left–right words, that is, irrespective of
the axis. We did not find any other significant effect or interaction,
all \( Fs < 1.00. \)
3.3. Discussion

We replicated the compatibility effect in SRTs in Experiment 2a’s vertical blocks. Again, the compatibility effect had its typical temporal signature in vertical blocks, increasing as a function of SRT, and this time it was non-existent for horizontal saccades. This pattern of results suggests that the compatibility effect could reflect a Simon effect because related differences between vertical and horizontal Simon effects based on visuo-spatial stimulus information and manual responses (cf. Wiegand & Wascher, 2005, 2007). However, it is also clear that our manipulations were too extreme with regard to the horizontal blocks in which with our conditions, no significant compatibility effect for horizontal blocks could be demonstrated for any of the deciles. This is different from Experiment 1 and most likely due to the easier target-color discrimination in the present than in the preceding experiment. To note, with the clearly perceptible black–white color difference between the targets in the present experiment, it was more likely that the response had been selected by the time that the word meaning became effective. This was in comparison to the more difficult blue-vs.-turquoise discrimination that was required in Experiment 1.

Moreover, in Experiment 2b, we observed a compatibility effect of irrelevant spatial word meaning on manual RTs. In contrast to the SRT effect, the manual compatibility effect increased as a function of RT in the horizontal blocks, too. This finding is in accordance with previous studies on manual RTs and word compatibility effects (e.g., Pellicano et al., 2009; Wühr & Biebl, 2011). The difference between manual RTs and SRTs could be due to a greater sensitivity of the saccadic control system than of the manual control system. For example, there could be a tighter coupling of the saccades than of the finger responses to the attentional system (e.g., Lleras, Moore, & Mordkoff, 2004; Rubichi et al., 1997) that renders the effect of spatial word meaning on saccades more similar to the influence of visuo-spatial code on manual responses.

Again, we found an advantage in horizontal as compared to vertical axis conditions. This was found with saccadic and manual responses. This finding is also suggestive of a Simon effect because left–right prevalence is typical of spatial S–R compatibility effects (cf. Nicoletti & Umiltà, 1984; Vu & Proctor, 2001).

4. General discussion

The simple aim of the present study was to test whether a Simon effect can be found for SRTs. This was the case. Building on prior work of Hodgson et al. (2009), we confirmed a spatial compatibility effect based on irrelevant spatial word meaning and saccade directions. In contrast to the study of Hodgson et al., color grouping of central word and only one of the peripheral boxes was ruled out as a contributing factor in the present experiments. This fact and the observation of two typical temporal signatures of Simon effects and spatial S–R compatibility, namely the different development of SRTs’ compatibility effects with vertical than horizontal codes over the SRT distribution (cf. Wiegand & Wascher, 2005, 2007), and the left–right prevalence (cf. Nicoletti & Umiltà, 1984; Vu & Proctor, 2001), were both suggestive that the compatibility effect in the present study reflected a spatial S–R compatibility effect of the Simon type. Also, in a control condition with manual responses, we were able to confirm the more typical pattern of Simon effects based on spatial word meaning and manual responses (cf. Pellicano et al., 2009).

One might want to ask whether our task was a spatial Stroop task rather than a Simon task. In a sense, the label for the task that we have used in the present study is equivocal because our task was partly similar to a spatial Stroop task and partly it resembled a Simon task. Our use of a word with an irrelevant spatial meaning is reminiscent of a major characteristic of a Stroop task (MacLeod, 1991). In a typical spatial Stroop task one major source of congruence concerns the degree of overlap between two sensory dimensions, the relevant and the irrelevant feature of the stimulus, for instance, the degree of overlap of spatial position and spatial meaning of a word in case of a spatial Stroop effect (see Hommel, 2011; Lu & Proctor, 1995). By contrast to this, the typical defining characteristic of the compatibility relation in a Simon task consists in the degree of overlap between an irrelevant spatial stimulus dimension and a spatial characteristic of the required response (Kornblum, 1992, 1994), for example, the degree of overlap of the spatial meaning of a word and the required response direction. Thus, in a way it is fine to use both of the above labels to refer to our task. Having said this, however, one should keep the important conclusions of the present study in mind: It was our declared aim to decide whether the compatibility effect reflected a sensorimotor effect or a sensory effect, and on the basis of the facts that (1) sensory identity of color words and color boxes was not critical for our correspondence effect, and (2) our compatibility effect showed characteristics of a typical Simon effect with physical stimulus position, we concluded that the effect reflected spatial S–R compatibility relations rather than only sensory correspondence relations. In this sense, the label Simon task seems to better fit the major characteristics of our task than the label spatial Stroop task, but as said, with that limitation in mind, nothing speaks against calling our task a spatial Stroop task.

In a broader sense, the present data are also in line with the assumption that attention might play a role in the Simon effect. The Simon effect in saccades would be predicted based on two inter-related assumptions: (1) an origin of the Simon effect relative to the direction of an attention shift (Nicoletti & Umiltà, 1989) and (2) a tight coupling between saccades and attention (Deubel & Schneider, 1996; Kowler et al., 2004). Assuming that attention shifts were also elicited by words but in a weaker form than by visuo-spatial code, the greater resemblance of the words’ Simon effect on SRTs (present Experiments 1 and 2a) than on RTs (Experiment 2b; Pellicano et al., 2009) to the Simon effect of visuo-spatial stimulus codes on manual RTs (cf. Wiegand & Wascher, 2005, 2007) would indeed suggest that saccades are indeed more prone to Simon effects based on attention shifts than are manual responses.

5. Conclusions

In the present study, we demonstrated a Simon effect of spatial word meaning on saccades. This Simon effect had the temporal signature of the standard Simon effect of visuo-spatial codes afforded by physical location on manual responses. This similarity is in accordance with embodied cognition theory because it shows that word meaning is probably grounded in sensory and sensorimotor representations, and thus capable of eliciting sensorimotor effects such as Simon effects in and by itself (cf. Ansorge et al., 2010; Barsalou, 1999).

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