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# The location-specific proportion congruence effect: Are left/right locations special?

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## Abstract

People reactively adjust attentional control based on the history of conflict experiences at different locations resulting in location-specific proportion compatibility (LSPC) effects. Weidler et al. (2022, *Journal of Experimental Psychology: Human Perception and Performance, 48*[4], 312–330) found that LSPC effects were larger when stimuli were presented on the horizontal axis (i.e., locations to left and right of fixation) compared with the vertical axis (i.e., locations above and below fixation). They proposed and provided initial evidence suggesting left/right locations may represent a special design feature that leads to stronger LSPC effects (i.e., horizontal precedence account). However, their use of horizontally oriented flanker stimuli, which required participants to traverse through the distracting flankers to select the central target selectively in the horizontal axis condition, may have contributed to the horizontal advantage they observed (i.e., gaze path account). The present study tested competing predictions of these two accounts. Experiment 1 used vertically oriented flanker stimuli and compared the findings with Weidler et al. The LSPC effect was larger for vertically oriented stimuli on the vertical axis, and horizontally oriented stimuli on the horizontal axis, supporting the gaze path account. Experiment 2 used flanker stimuli that required participants to traverse through distracting flankers regardless of the axis on which stimuli were presented. The LSPC effect was equivalent between the vertical axis and horizontal axis conditions. These results further supported the gaze path account and suggest that the critical design feature for amplifying LSPC effects is not left/right locations per se, but rather use of stimuli/axis combinations that encourage processing of the distractor dimension.


**Keywords** Context-specific proportion compatibility · Location-specific proportion compatibility · Conflict · Reactive control

Navigating our lives often requires quick adjustments of attention in response to environmental cues. In the laboratory, attentional control is commonly assessed using tasks such as flanker (e.g., respond to the identity of a central target and not the identity of surrounding distractors). Compatible trials (e.g., <<<<<) are responded to faster and often more accurately than are incompatible trials (e.g., >><>>) on which the target and distractors conflict. There is now a large body of evidence showing that control is adjusted based on learned associations between environmental features and conflict likelihood (for review, see Bugg & Crump, 2012; see also Bugg & Egner, 2021). Location is one such feature that triggers control adjustments, as evidenced by location-specific proportion congruence (LSPC) effects. The LSPC effect is the finding that the compatibility effect (i.e., magnitude of RT slowing on incompatible relative to compatible trials) is reduced in locations that are mostly incompatible (MI) compared with mostly compatible (MC). According to the episodic retrieval account, a more focused control setting (e.g., one that weights the target to a greater degree than the flankers) is retrieved when a stimulus appears in the MI location whereas a more relaxed control setting is retrieved in the MC location, and these settings correspond to the history of selection in each location (i.e., the control setting used most frequently when responding to stimuli in a location; Crump et al., 2006; Crump & Milliken, 2009; but see Schmidt & Lemercier, 2019, for an alternative account).

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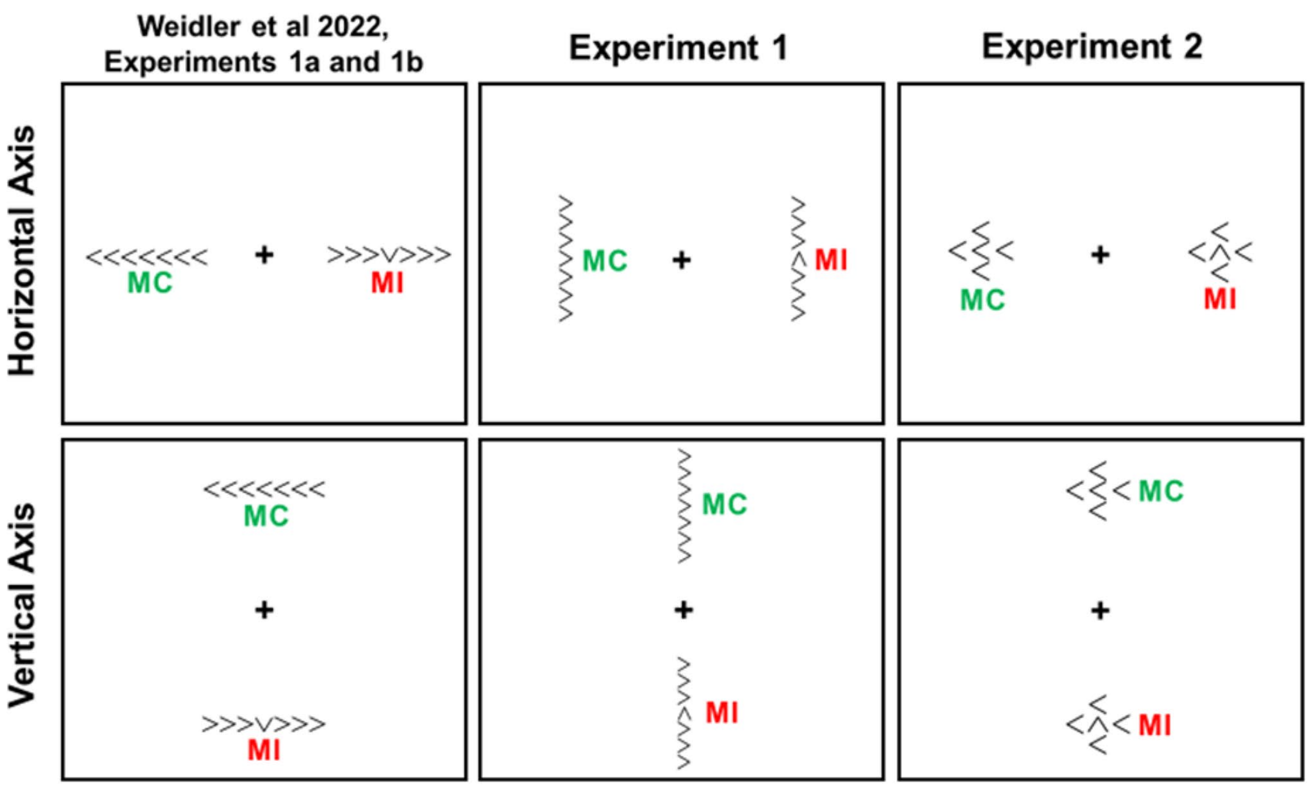


**Fig. 1** A schematic example of the two locations in the three experiments of interest to the current study. The left panel depicts Experiments 1a and 1b from Weidler et al. (2022), which used horizontally oriented stimuli. The middle panel depicts Experiment 1 of the current study, which used vertically oriented stimuli. The right panel depicts Experiment 2 of the current study, which used stimuli with distractor arrows above, below, to the left, and to the right of the central target. Each of these experiments used a between subject manipulation where one condition presented stimuli in locations along an invisible horizontal axis (upper row) or locations along an invisible vertical axis (lower row). Although the figure shows examples of two stimuli in each panel, during the experiment stimuli were shown one at a time. (Color figure online)

The majority of LSPC studies have defined location in terms of upper versus lower (e.g., MC location is above fixation and MI location is below[1]). Recent evidence raised the possibility that the use of upper and lower locations may have inadvertently decreased the magnitude of LSPC effects. Specifically, Weidler et al. (2022) found that LSPC effects were larger when stimuli were presented along the horizontal (i.e., left and right locations were used) than vertical (i.e., upper and lower locations were used, as in most prior research) axis, which we refer to as the horizontal advantage, for short. One account of this pattern is that there is a general benefit for learning and/or triggering of adjustments in control when space is defined horizontally, which we refer to as the *horizontal precedence account*. According to this account (Weidler et al., 2022), the horizontal advantage may relate to the less permeable nature of the left/right as compared with upper/lower hemifields (e.g., Hughes & Zimba, 1987; Tassinari et al., 1987), or to cognitive factors such as the coding of space along the horizontal as compared with vertical axes (e.g., Nicoletti & Umiltà, 1984; Rubichi et al., 2005).

An alternative account, however, is that the horizontal advantage hinges critically on the orientation of the stimuli. Weidler et al. (2022) used horizontally oriented flanker stimuli (i.e., distractor arrows located to the left and right of the central target arrow; see Fig. 1, left panel). Consider the path of a participant's gaze from the central fixation to the target arrow during this task. With horizontally oriented stimuli, distractors reside in the visual path to the target

[1] The earliest study to assess compatibility effects in MC and MI locations (Corballis & Gratton, 2003) used left and right locations because they aimed to have a location in the left and right visual hemifields. The first studies to refer to the LSPC effect (Crump et al., 2006; Crump et al., 2008; Crump & Milliken, 2009) used upper and lower locations, and the majority of the field followed suit (e.g., Bugg et al., 2020; Crump et al., 2017; Diede & Bugg, 2016, 2017, 2019; Dreisbach et al., 2018; Gottschalk & Fischer, 2017; Hübner & Mishra, 2016; Hutcheon & Spieler, 2017; Surrey et al., 2017; Surrey et al., 2019; Vel Grajewska et al., 2011; Vietze & Wendt, 2009; Weidler et al., 2021). However, a minority of studies have used left and right locations (e.g., King et al., 2012; Wendt et al., 2008).

selectively when stimuli are located on the horizontal axis (i.e., in left and right locations). This necessity to traverse the distractor arrows to select the target could explain why Weidler et al. observed larger compatibility effects along the horizontal axis than the vertical axis, a pattern that could reasonably have led to the larger LSPC effects as well. Hereafter we refer to this as the *gaze path account*. This account yields a prediction that competes with that of the horizontal precedence account: LSPC effects will not always be larger on the horizontal than vertical axis. Rather, the magnitude will depend on whether stimulus orientation and axis (i.e., stimulus locations) align. Weidler et al. discussed this possibility in their study, but given that all flanker stimuli were horizontally oriented, they could not disentangle the horizontal precedence account from the gaze path account (i.e., the horizontal axis was confounded with a need to "gaze through" the distractors).

To distinguish between the horizontal precedence account and the distractor gaze path account, we conducted two experiments. In Experiment 1 (see Fig. 1, middle panel), the flanker stimuli were vertically oriented, such that the distractor arrows were in the gaze path of the participant when using a vertical axis, but not when using a horizontal axis, opposite to Weidler et al. (2022). In Experiment 2 (see Fig. 1, right panel), the flanker stimuli were comprised of four distractor arrows, one in each cardinal direction relative to the target, such that distractor arrows resided in the gaze path for both vertical and horizontal axis conditions. We found evidence that conflict in the gaze path rather than the use of the horizontal axis per se dictated the size of the LSPC effect, consistent with the gaze path account, and suggesting left/right locations are not special.

## Experiment 1

In Experiment 1, the flanker stimuli were vertically oriented (see Fig. 1, middle panel) and half the participants were shown stimuli along the horizontal axis (i.e., left and right locations) whereas the other half were shown stimuli along the vertical axis (i.e., upper and lower locations). The horizontal precedence account predicts a horizontal advantage, such that the LSPC effect should be larger for the horizontal axis than the vertical axis. The gaze path account predicts the opposite—the LSPC effect should be larger for the vertical axis than the horizontal axis.

### Method

#### Participants

We based our sample size on a power analysis of Experiments 1a and 1b of Weidler et al. (2022). Using G*Power (Version 3.1.9.7; Faul et al., 2007), we calculated that to have .80 power to detect a comparably sized effect to their difference in LSPC effects across axis conditions ($\eta_p^2$ = 0.05), 26 participants are required. To be conservative, we aimed for at least 32 participants in each condition. All participants were 18–25 years old and had normal or corrected-to-normal vision.

Sixty-seven undergraduates from Towson University were individually tested in a laboratory space. A participant was removed from analysis if they made errors on 33.3% or more of the incompatible trials (cf. Weidler et al., 2022). One participant was removed in the horizontal axis condition (59.07% errors on incompatible trials). This resulted in 34 participants in the vertical axis condition (Age $M$ = 18.69, $SD$ = 1.12, 28 females, six males) and 32 participants in the horizontal axis condition (Age $M$ = 18.56, $SD$ = 0.95; 28 females, three males, one nonbinary).

#### Stimuli and procedure

Experiments were coded and data was collected using PsychoPy Version 2.10 (Peirce et al., 2019). Each trial began with a 1 cm fixation cross presented centrally for 1,000 ms. Participants were not explicitly instructed to maintain fixation during the experiment. Next a vertically oriented flanker stimulus was presented until response. Flanker stimuli comprised a central arrow facing one of four directions flanked vertically by six arrows facing one of four directions (three on each side of the target). Each of the four targets appeared equally often at each of the two locations. On compatible trials, the identity of the flanker arrows and the target arrow matched. On incompatible trials, the identity of the flanker arrows and the target arrows mismatched. The identity of the flanker arrows was equally likely to be any of the other three directions (e.g., up, left, or right flanker arrows for a down target arrow). The stimulus was 1.5-cm wide and 6-cm tall (see Fig. 1, middle panel). Participants were instructed to respond to the identity of the central arrow as quickly as possible using their right index finger. The 2, 4, 6, and 8 keys on the number pad represented down, left, right, and up, respectively. Participants were seated approximately 83 cm from a screen that was 53.34-cm wide and 30.45-cm tall.

Participants first completed a 12-trial practice block where the trials were chosen randomly from trials that appeared in the main experiment. Participants next completed three 96-trial blocks. In each block, 48 trials appeared at a 75% compatible MC location and 48 trials appeared at a 25% compatible MI location (randomly intermixed).

In the vertical axis condition, one location was 4-cm above fixation, and the other location was 4-cm below fixation. In the horizontal axis condition, one location was 4-cm left of fixation, and the other location was 4-cm right of fixation. It was counterbalanced between subjects which

**Table 1** Experiment 1 descriptive statistics

| Axis | PC | Trial Type | RT (*SE*) in ms | Error (*SE*) in % |
|---|---|---|---|---|
| Vertical | MC | Compatible | 762 (23) | 0.44 (0.17) |
| | | Incompatible | 1009 (28) | 3.66 (0.66) |
| | | *Compatibility Effect* | *248* | *3.22* |
| | MI | Compatible | 775 (23) | 0.33 (0.16) |
| | | Incompatible | 969 (26) | 3.02 (2.70) |
| | | *Compatibility Effect* | *194* | *2.70* |
| | | **LSPC Effect** | **54** | **0.52** |
| Horizontal | MC | Compatible | 667 (17) | 0.49 (0.19) |
| | | Incompatible | 828 (23) | 3.70 (1.11) |
| | | *Compatibility Effect* | *161* | *3.20* |
| | MI | Compatible | 675 (17) | 0.79 (0.29) |
| | | Incompatible | 809 (21) | 3.16 (1.09) |
| | | *Compatibility Effect* | *134* | *2.37* |
| | | **LSPC Effect** | **27** | **0.83** |

*Note*. Mean RT (ms) and error rate (%) in each condition for Experiment 1 (*SE*s in parentheses)

location was MC or MI, and whether the axis was vertically oriented or horizontally oriented.

The design of the experiment was a 2 × 2 × 2 mixed design, with a between-subjects factor of axis orientation (vertical or horizontal) and within-subjects factors of PC (MC or MI) and trial type (compatible or incompatible).

## Results

RTs between 200 and 2,000 ms (cf. e.g., Colvett & Bugg, 2021; Weidler et al., 2022) were included in the analysis. The RT trim removed 1.20% and 2.51% of trials in the vertical and horizontal axis conditions, respectively. See Table 1 for descriptive statistics.

For analyses of reaction time, only correct responses were analyzed. For theoretically relevant null interactions, we additionally presented Bayes Factors. We reported Bayesian evidence for the null hypothesis compared with evidence of the alternative hypothesis ($BF_{01}$). A value between 1 and 3 indicates anecdotal evidence for the null hypothesis and a value between 3 and 10 indicates substantial evidence for the null hypothesis (Wagenmakers et al., 2011). We calculated Bayes factors and all other statistics using JASP 0.16.3 (JASP Team, 2022).

We ran a 2 × 2 × 2 mixed-effects analysis of variance (ANOVA), with within-subjects factors of PC (MC or MI) and trial type (compatible or incompatible) and a between subject factor of axis (vertical or horizontal) on the data from Experiment 1. Because we had a priori hypotheses that we would observe a significant LSPC effect in both the vertical and horizontal axis conditions, we additionally ran separate 2 × 2 repeated-measures ANOVAs for the vertical and horizontal axis conditions. In addition, we performed a cross-experimental analysis comparing the current data (vertically oriented stimuli on vertical vs. horizontal axis) to the data from Weidler et al. (2022) (horizontally oriented stimuli on a vertical vs. horizontal axis) so that we could compare the relative advantages of a given axis as a function of stimulus orientation (vertically oriented or horizontally oriented).

### Reaction time

There was a main effect of trial type, $F(1, 64) = 493.40$, $p < .001$, $\eta_p^2 = .89$, such that compatible trials ($M = 721$, $SE = 16$) were responded to faster than incompatible trials ($M = 906$, $SE = 21$). There was a main effect of PC, $F(1, 64) = 5.31$, $p = .025$, $\eta_p^2 = .08$, such that trials at the MC location ($M = 819$, $SE = 23$) were responded to slower than trials at the MI location ($M = 809$, $SE = 21$). There was also a main effect of axis, $F(1, 64) = 19.06$, $p < .001$, $\eta_p^2 = .23$, such that responses were slower in the vertical axis condition ($M = 878$, $SE = 23$) than the horizontal axis condition ($M = 745$, $SE = 17$). There was a significant interaction between axis and trial type, $F(1, 64) = 19.55$, $p < .001$, $\eta_p^2 = .23$, such that the compatibility effect was larger in the vertical axis condition ($M = 221$, $SE = 10$) than the horizontal axis condition ($M = 147$, $SE = 8$). There was an LSPC effect, as evidenced by the significant interaction between PC and trial type, $F(1, 64) = 32.99$, $p < .001$, $\eta_p^2 = .34$, such that the compatibility effect was larger at the MC location ($M = 206$, $SE = 11$) than the MI location ($M = 165$, $SE = 9$). There was not an interaction between axis and PC, $F(1, 64) = 0.75$, $p = .391$, $\eta_p^2 = .01$, $BF_{01} = 4.93$. The three-way interaction between axis, PC, and trial type, $F(1, 64) = 3.55$, $p = .064$, $\eta_p^2 = .05$, $BF_{01} = 1.92$, did not reach significance and the Bayesian evidence was anecdotal, suggesting that the LSPC effect was nominally but not statistically larger in the vertical axis condition ($M = 54$, $SE = 8$) compared with the horizontal axis condition ($M = 27$, $SE = 12$; see Fig. 2, left panel).

Examining each axis separately, we confirmed that there was a significant LSPC effect (PC × trial type interaction) for the vertical axis, $F(1, 33) = 42.51$, $p < .001$, $\eta_p^2 = .56$, such that the compatibility effect was larger at the MC location ($M = 248$, $SE = 14$) compared with the MI location ($M = 194$, $SE = 13$). There was also a significant LSPC effect for the horizontal axis, $F(1, 31) = 5.51$, $p = .026$, $\eta_p^2 = .15$, such that the compatibility effect was larger at the MC location ($M = 161$, $SE = 13$) compared with the MI location ($M = 134$, $SE = 11$).

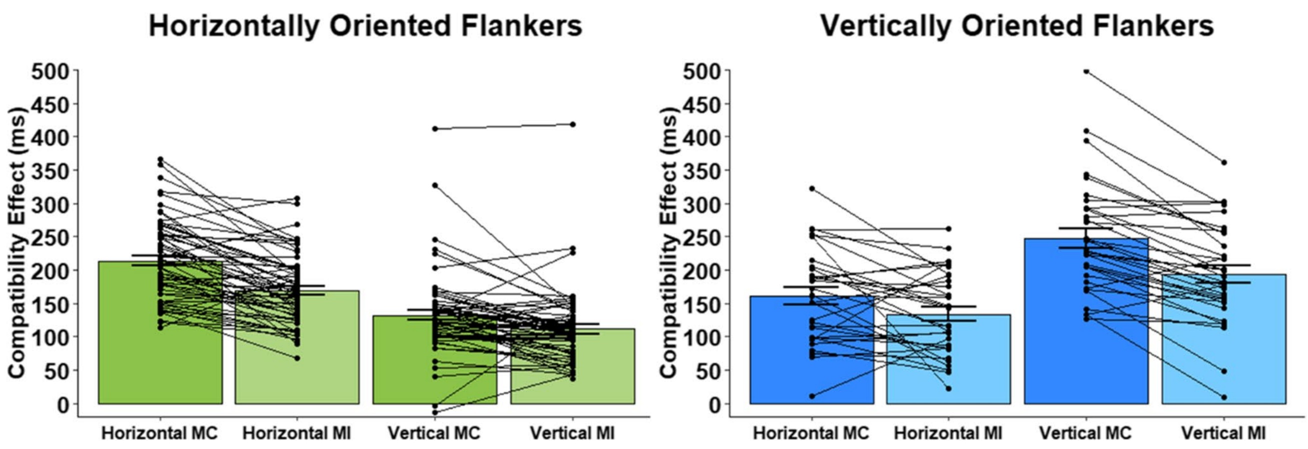


**Fig. 2** The colored bars depict mean compatibility effects as a function of axis (whether the two locations were presented on a horizontal axis or a vertical axis), location PC (MC or MI), and stimulus orientation (whether the flanker stimuli were horizontally oriented [Weidler et al., 2022, left panel] or vertically oriented [Experiment 1, right panel]). Error bars represent standard error of the mean. Each line connects one participant's data in the MC and MI conditions. When assessing compatibility effects across experiments, a significant interaction between axis, stimulus orientation, and PC was found indicating that the LSPC effect was larger on the horizontal axis than the vertical axis when the stimuli were horizontally oriented but larger on the vertical axis than the horizontal axis when the stimuli were vertically oriented

### Error rate

There was a main effect of trial type, $F(1, 64) = 34.03$, $p < .001$, $\eta_p^2 = .35$, such that compatible trials ($M = 0.51\%$, $SE = 0.15\%$) were responded to more accurately than incompatible trials ($M = 3.38\%$, $SE = 0.61\%$), but there was not a main effect of PC, $F(1, 64) = 0.92$, $p = .342$, $\eta_p^2 = .01$, or axis, $F(1, 64) = 0.07$, $p = .786$, $\eta_p^2 < .01$. All interactions were nonsignificant: axis and trial type, $F(1, 64) = 0.03$, $p = .862$, $\eta_p^2 < .01$, $BF_{01} = 5.27$; and PC and trial type, $F(1, 64) = 2.09$, $p = .153$, $\eta_p^2 = .03$, $BF_{01} = 3.37$; axis and PC, $F(1, 64) = 0.23$, $p = .631$, $\eta_p^2 < .01$, $BF_{01} = 5.29$; axis, PC, and trial type ($F(1, 64) = 0.11$, $p = .736$, $\eta_p^2 < .01$, $BF_{01} = 4.59$.

Looking at each axis separately, there was a non-significant interaction between PC and trial type for the vertical axis, $F(1, 33) = 0.52$, p = .477, $\eta_p^2 = .02$, $BF_{01} = 3.29$, and for the horizontal axis, $F(1, 31) = 2.01$, $p = .167$, $\eta_p^2 = .06$, $BF_{01} = 3.25$.

### Cross experiment analysis

Experiments 1a and 1b[2] from Weidler et al. (2022) provide an interesting comparison to Experiment 1. Both studies presented stimuli at vertical and horizontal axes, but they differed in terms of whether the stimuli were oriented vertically (as in Experiment 1) or horizontally (as in Weidler et al., 2022). Comparing the LSPC effect across experiments enabled us to examine the relative advantages of a given axis (vertical vs. horizontal) as a function of stimulus orientation (vertically oriented or horizontally oriented).

Rather than include trial type as a factor, we simplified the analysis for ease of interpretation by submitting compatibility effects to a 2 stimulus orientation (vertical or horizontal) × 2 axis (vertical or horizontal) × 2 PC (MC or MI) mixed ANOVA with PC as the single within-subjects factor. We conducted separate ANOVAs for RT and error rate.

### Reaction time

Of greatest theoretical relevance, there was a significant three-way interaction between axis, stimulus orientation, and PC $F(1, 186) = 9.75$, $p = .002$, $\eta_p^2 = .05$, such that the LSPC effect was larger using a vertical axis (54 ms) than a horizontal axis (27 ms) when using vertically oriented stimuli, but larger using a horizontal axis (44 ms) than a vertical axis (21 ms) when using horizontally oriented stimuli (see Fig. 2).

In addition, there was a main effect of PC (here, this refers to the LSPC effect), $F(1, 186) = 84.13$, $p < .001$, $\eta_p^2 = .31$, such that the compatibility effect was larger at the MC location ($M = 184$, $SE = 6$) compared with the MI location ($M = 149$, $SE = 5$). There was also a main effect of stimulus orientation, $F(1, 186) = 9.55$, $p = .002$, $\eta_p^2 = .05$, such that the compatibility effect was larger using vertically oriented flankers ($M = 185$, $SE = 9$) compared with horizontally oriented flankers ($M = 157$, $SE = 6$). There was no effect of axis, $F(1, 186) = 0.04$, $p = .846$, $\eta_p^2 < .01$. There was a

[2] The experiments from Weidler et al. (2022) included an additional factor that was not used in the current study (i.e., whether locations were on the same or different sides of the central fixation). That factor was ignored for the purposes of this analysis, and the data were collapsed into two groups (vertical axis and horizontal axis).

significant interaction between stimulus orientation and axis $F(1, 186) = 65.32$, $p < .001$, $\eta_p^2 = .26$, such that the difference in compatibility effects between vertically and horizontally oriented flankers was larger in the vertical axis condition (27 ms) than the horizontal axis condition (−23 ms). The interactions between PC and axis, $F(1, 186) = 0.04$, $p = .839$, $\eta_p^2 < .01$, $BF_{01} = 5.07$, and between PC and stimulus orientation, $F(1, 186) = 0.94$, $p = .333$, $\eta_p^2 = .01$, $BF_{01} = 4.20$, were nonsignificant.

### Error rate

The three-way interaction between axis, stimulus orientation, and PC was not significant, $F(1, 186) < 0.01$, $p = .975$, $\eta_p^2 < .01$, $BF_{01} = 4.74$. The main effect of PC was significant, $F(1, 186) = 6.70$, $p = .010$, $\eta_p^2 = .04$, such that the compatibility effect was larger at the MC location ($M = 4.20\%$, $SE = 0.42\%$) compared with the MI location ($M = 3.29\%$, $SE = 0.31\%$). There was not a main effect of axis, $F(1, 186) = 0.72$, $p = .397$, $\eta_p^2 < .01$, or stimulus orientation, $F(1, 186) = 3.84$ , $p = .051$, $\eta_p^2 = .02$. In addition, there was not an interaction between stimulus orientation and axis, $F(1, 186) = 1.21$, $p = .273$, $\eta_p^2 = .01$, $BF_{01} = 1.96$, PC and axis, $F(1, 186) = 0.20$, $p = .654$, $\eta_p^2 < .01$, $BF_{01} = 5.95$, or PC and stimulus orientation, $F(1, 186) = 0.29$, $p = .592$, $\eta_p^2 < .01$, $BF_{01} = 5.16$.

## Discussion

Experiment 1 used vertically oriented stimuli and the findings provided initial evidence against the horizontal precedence account. The compatibility effect was significantly smaller in the horizontal axis condition compared with the vertical axis condition. In addition, the LSPC effect was nominally, though not significantly, smaller in the horizontal axis condition ($\eta_p^2 = .15$) than the vertical axis condition ($\eta_p^2 = .56$). The cross-experiment analysis comparing Experiment 1 to Weidler et al. (2022) painted a clearer picture: The LSPC effect was larger in the vertical axis condition than the horizontal axis condition when using vertically oriented stimuli, but it was larger in the horizontal axis condition than the vertical axis condition when using horizontally oriented stimuli. These results are consistent with the gaze path account but challenge the horizontal precedence account as that account predicted a horizontal advantage for *both* axes. To further test these accounts, we conducted Experiment 2.

# Experiment 2

Experiment 1 used vertically oriented stimuli and compared the findings with Weidler et al. (2022), who used horizontally oriented stimuli. The LSPC effect was larger for vertically oriented stimuli on the vertical axis, and horizontally oriented stimuli on the horizontal axis, supporting the gaze path account. However, the results do not negate the possibility that left/right locations (i.e., the horizontal axis) may be special—that is, the results of Experiment 1 and Weidler et al. (2022) could be explained by a combination of the gaze path and horizontal precedence accounts, as the two are not mutually exclusive. To further test the accounts, in Experiment 2 we used a single set of flanker stimuli that comprised distractor arrows surrounding the central target in four directions (see Fig. 1, right panel). These new stimuli allowed us to hold constant the conflict in the gaze path between the vertical and horizontal axis conditions. If conflict in the gaze path drives the pattern of LSPC effects (i.e., whether a horizontal or vertical advantage is found), then the LSPC effect should be equivalent between the horizontal and vertical axis conditions (i.e., there should not be an advantage for one over the other). However, if left/right locations are special, as the horizontal precedence account suggests, then the LSPC effect should be larger on the horizontal axis compared with the vertical axis.

## Method

### Participants

As noted in the preceding introduction, one of the competing accounts (gaze path account) anticipates a theoretically relevant null effect. We thus increased the sample size by 50% to have sufficient power to find evidence against the gaze path account if such evidence exists. Ninety-six undergraduates from Towson University participated, 48 in the vertical axis condition (Age $M = 19.46$, $SD = 1.38$; 32 female, 13 male, three other) and 48 in the horizontal axis condition (Age $M = 20.04$, $SD = 2.61$; 35 female, 12 male, one other). All participants met our inclusion criteria. This experiment was preregistered (https://osf.io/fh4ju).

### Stimuli, procedure, and design

Stimuli, procedure, and design were identical to Experiment 1, except for a change to the flanker stimuli. The central target arrow was now surrounded by four flanker arrows, one each above, below, to the left, and to the right of the target arrow (see Fig. 1, right panel). The flanker stimuli were 4.5-cm tall and 4.5-cm wide.

## Results

The RT trim removed 2.11% and 2.37% of trials in the vertical and horizontal axis conditions, respectively. See Table 2 for descriptive statistics.

**Table 2** Experiment 2 descriptive statistics

| Axis | PC | Trial Type | RT (SE) in ms | Error (SE) in % |
|---|---|---|---|---|
| Vertical | MC | Compatible | 700 (18) | 0.28% (0.07%) |
| | | Incompatible | 827 (18) | 2.10% (0.45%) |
| | | *Compatibility Effect* | *128 (8)* | *1.82% (0.45%)* |
| | MI | Compatible | 703 (18) | 0.05% (0.06%) |
| | | Incompatible | 811 (17) | 1.81% (0.32%) |
| | | *Compatibility Effect* | *108 (7)* | *1.76% (0.32%)* |
| | | **LSPC Effect** | **20** | **0.06%** |
| Horizontal | MC | Compatible | 667 (18) | 0.35% (0.20%) |
| | | Incompatible | 806 (19) | 1.97% (0.43%) |
| | | *Compatibility Effect* | *139 (9)* | *1.62% (0.38%)* |
| | MI | Compatible | 672 (18) | 0.68% (0.43%) |
| | | Incompatible | 789 (19) | 1.51% (0.31%) |
| | | *Compatibility Effect* | *117 (7)* | *0.83% (0.33%)* |
| | | **LSPC Effect** | **23** | **0.79%** |

*Note*. Mean RT (ms) and error rate (%) in each condition for Experiment 2 (*SE*s in parentheses)

We ran separate 2 × 2 × 2 mixed-effects ANOVAs with within-subjects factors of PC (MC or MI) and trial type (compatible or incompatible) and a between-subject factor of axis (vertical or horizontal) for reaction time and error rate. As we again had a priori hypotheses that LSPC effects would be present in both the vertical and horizontal axis conditions, we additionally ran separate 2 × 2 repeated-measures ANOVAs for the vertical and horizontal axis conditions.

### Reaction time

There was a main effect of trial type, $F(1, 94) = 726.79$, $p < .001$, $\eta_p^2 = .89$, such that compatible trials ($M = 686$, $SE = 13$) were responded to faster than incompatible trials ($M = 809$, $SE = 13$). There was a main effect of PC, $F(1, 94) = 4.57$, $p = .035$, $\eta_p^2 = .05$, such that trials at the MC location ($M = 750$, $SE = 15$) were responded to more slowly than trials at the MI location ($M = 744$, $SE = 14$). There was no effect of axis, $F(1, 94) = 1.20$, $p = .276$, $\eta_p^2 = .01$. There was a significant interaction between PC and trial type, $F(1, 94) = 12.56$, $p < .001$, $\eta_p^2 = .12$, such that the compatibility effect was larger at the MC location ($M = 133$, $SE = 6$) than the MI location ($M = 112$, $SE = 5$) (i.e., there was an LSPC effect). There was not an interaction between axis and PC ($F(1, 94) = 0.01$, $p = .907$, $\eta_p^2 < .01$, $BF_{01} = 6.54$), or between axis and trial type, $F(1, 94) = 1.29$, $p = .259$, $\eta_p^2 = .01$, $BF_{01} = 2.57$. Most importantly, consistent with the gaze path account, there was no interaction between axis, PC, and trial type, $F(1, 94) = 0.06$, $p = .815$, $\eta_p^2 < .01$, $BF_{01} = 4.92$ (see Fig. 3).

Examining each axis separately, there was a significant interaction between PC and trial type, $F(1, 47) = 5.97$, $p = .019$, $\eta_p^2 = .11$, for the vertical axis such that the compatibility effect was larger at the MC location ($M = 128$, $SE = 8$) compared with the MI location ($M = 108$, $SE = 7$). There was also a significant interaction between PC and trial type, $F(1, 47) = 6.62$, $p = .013$, $\eta_p^2 = .12$, for the horizontal axis such that the compatibility effect was larger at the MC location ($M = 139$, $SE = 9$) compared with the MI location ($M = 117$, $SE = 7$).

### Error rate

There was a significant effect of trial type, $F(1, 94) = 46.03$, $p < .001$, $\eta_p^2 = .33$, such that compatible trials ($M = 0.34\%$, $SE = 0.17\%$) were responded to more accurately than incompatible trials ($M = 1.85\%$, $SE = 0.27\%$). There was no effect of PC, $F(1, 94) = 1.23$, $p = .271$, $\eta_p^2 = .01$, or axis, $F(1, 94) = 0.04$, $p = .835$, $\eta_p^2 < .01$. There were also nonsignificant interactions between axis and PC, $F(1, 94) = 0.42$, $p = .521$, $\eta_p^2 < .01$, $BF_{01} = 5.69$, axis and trial type, $F(1, 94) = 1.62$, $p = .207$, $\eta_p^2 = .02$, $BF_{01} = 2.02$, and PC and trial type, $F(1, 94) = 2.38$, $p = .126$, $\eta_p^2 = .03$, $BF_{01} = 3.28$. There was not a three-way interaction between axis, PC, and trial type, $F(1, 94) = 1.74$, $p = .191$, $\eta_p^2 = .02$, $BF_{01} = 2.45$.

Examining each axis separately, there was not a significant interaction between PC and trial type, $F(1, 47) = 2.01$, $p = .163$, $\eta_p^2 = .04$, $BF_{01} = 4.45$, for the vertical axis or horizontal axis, $F(1, 47) = 3.32$, $p = .075$, $\eta_p^2 = .07$, $BF_{01} = 1.38$. That is, in neither case was there a significant LSPC effect.

## Discussion

Experiment 2 used a novel set of stimuli that placed distractor arrows in the gaze path to the target in both the vertical and horizontal axis conditions, resulting in equivalent compatibility effects between the two axis conditions. Most critically, we found no difference in LSPC effects between the horizontal and vertical axis conditions—that is, there was neither a horizontal nor vertical advantage. This finding directly contradicts the horizontal precedence account, as the account predicts that presenting stimuli on the horizontal axis should produce a horizontal advantage. This null interaction is, however, consistent with the gaze path account. Notably, the Bayesian evidence for the interaction suggested "substantial" support for the null hypothesis.

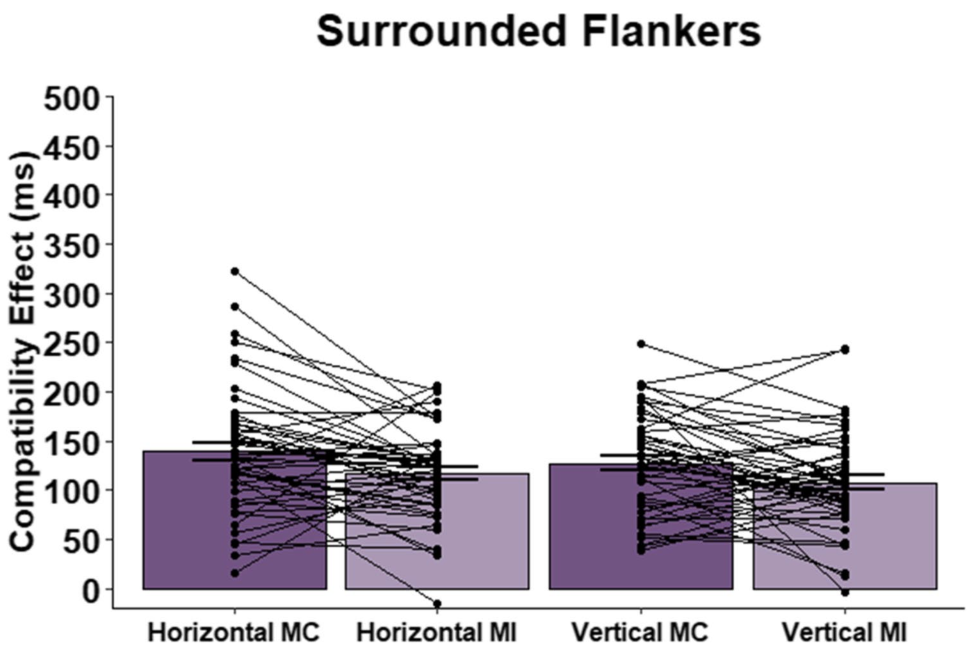


**Fig. 3** The colored bars depict mean compatibility effects as a function of axis (i.e., whether the two locations are presented on a horizontal axis or a vertical axis) and location PC (MC or MI) in Experiment 2. Error bars represent standard error of the mean. Each line connects one participant's data in the MC and MI conditions. A significant LSPC effect was observed using both the vertical and horizontal axis layouts, and the effect did not differ between the two conditions. (Color figure online)

## General discussion

Weidler et al. (2022) found evidence favoring the horizontal precedence account, suggesting an advantage in the magnitude of the LSPC effect for left/right locations (i.e., the horizontal axis) compared with upper/lower locations (i.e., the vertical axis). This horizontal advantage, alongside evidence of an otherwise elusive transfer effect Weidler et al. observed using left/right locations[3], raised the possibility that left/right locations may be special for learning and triggering flexible attentional control. However, the findings from the current study challenge this account and are best explained by an alternative gaze path account. The gaze path account posits that it was not the use of left/right locations (i.e., the horizontal axis) per se that yielded the horizontal advantage in Weidler et al. but rather left/right locations in tandem with horizontally oriented stimuli. These stimuli encouraged participants to process the distractor arrows selectively in the horizontal axis condition, which amplified compatibility effects and the LSPC effect along that axis.

In Experiment 1, we examined whether a vertical advantage would instead be observed for vertically oriented stimuli, requiring participants to traverse the distractors selectively in the vertical axis condition (i.e., upper/lower locations). The compatibility effect was significantly larger and the LSPC effect was nominally larger in the vertical axis condition compared with the horizontal axis condition. In addition, in a cross-experiment analysis comparing Experiment 1 to Weidler et al. (2022) where the flanker stimuli were oriented horizontally, the LSPC effect was significantly larger for the vertical axis when using vertically oriented stimuli (i.e., vertical advantage) but significantly larger for the horizontal axis when using horizontally oriented stimuli (i.e., horizontal advantage). In Experiment 2, we used a new set of flanker stimuli that allowed us to match the conflict in the gaze path between axis conditions, and we found that neither axis resulted in a larger compatibility or LSPC effect. Collectively, these results suggest that contrary to the horizontal precedence account, LSPC effects were not consistently larger when locations were presented on a horizontal axis (i.e., when stimuli were presented in left/right locations). Instead, consistent with the gaze path account, the effect of axis was

[3] Crump and Milliken (2009) found an LSPC effect for a novel set of unbiased (i.e., "diagnostic") stimuli presented in upper and lower locations that were MC or MI. This evidence for transfer represents the strongest evidence for a location-specific control mechanism in LSPC paradigms (see Braem et al., 2019). However, using upper and lower locations like Crump and Milliken, several subsequent experiments were not able to reproduce this finding (see Bugg et al., 2020; Crump et al., 2017; Hutcheon & Spieler, 2017).

modulated by whether the orientation of the stimulus was aligned with the axis, placing conflict in the gaze path.

One implication of the gaze path account is that LSPC effects are more robust when task parameters produce more conflict on incompatible (relative to compatible) trials (i.e., larger compatibility effects). When stimulus orientation and axis aligned to place conflict in the gaze path, the basic compatibility effect was larger both in Experiment 1 and in Weidler et al. (2022), as was the LSPC effect. This apparent correspondence between the magnitude of the compatibility effect and the magnitude of the LSPC effect was further evidenced in a series of exploratory correlational analyses, which revealed significant positive correlations in each experiment and an overall correlation of $r(284) = .40$, $p < .001$, 95% CI [.30, .50] when collapsed across all experiments (see Supplemental Materials for further details and scatterplots). These patterns suggest that LSPC effects are larger when there is more conflict to be controlled (e.g., when horizontally oriented stimuli are presented along the horizontal axis or vertically oriented stimuli are presented along the vertical axis). While it remains uncertain why LSPC effects may be more pronounced when there is more conflict, a few possible explanations merit consideration.

One possibility is that the conflict itself fundamentally alters the magnitude of the location-based adjustments such that larger adjustments in attentional control occur to the degree that conflict is greater (cf. Botvinick et al., 2001). A second possibility is that participants may be more inclined to engage control in the presence of greater conflict—in other words, larger compatibility effects may signal a greater need for control. A third possibility is that the magnitude of conflict may influence the learning process underlying effects such as the LSPC effect, which involves forming associations between locations and conflict likelihood. This possibility is inspired by the Hebbian learning model of Verguts and Notebaert (2008), wherein conflict serves to signal the need to strengthen task-relevant connections. More conflict may lead to greater strengthening and consequently stronger associations between locations and conflict likelihood. Future research is needed to test these possibilities, but the present findings are important in suggesting that strengthening the conflict experience may lead to stronger LSPC effects.

In line with this notion, it is interesting that compatibility effects *and* LSPC effects were smaller in Experiment 2 compared with Experiment 1 and Weidler et al. (2022). More specifically, in Experiment 2, the mean compatibility effect was 123 ms and the effect size for the LSPC effect was $\eta_p^2 = .12$. In contrast, in Experiment 1 (vertical axis/vertically oriented stimuli) the mean compatibility effect was 221 ms and the effect size for the LSPC effect was $\eta_p^2 = .56$, and in Weidler et al. (horizontal axis/horizontally oriented stimuli) the mean compatibility effect was 192 ms and the effect size for the LSPC effect was $\eta_p^2 = .43$. The new stimuli we created for Experiment 2 differed from those used in Experiment 1 and Weidler et al. in that there was only one distractor adjacent to the target in each direction compared with three distractors (in the vertical axis/vertically oriented stimuli and horizontal axis/horizontally oriented stimuli) in the gaze path. The smaller compatibility effects in Experiment 2 compared with Experiment 1 likely reflect this difference.

The reduction in the compatibility effect in Experiment 2 suggests that it was easier to respond to the surrounded flanker stimuli. One may wonder if the use of a relatively less difficult task precluded observing a difference in LSPC effects between the vertical and horizontal conditions (e.g., a potential horizontal advantage) in Experiment 2.[4] We think this possibility is unlikely for three reasons. First, although compatibility effects were relatively small in Experiment 2 (compared with Weidler et al., 2022, and Experiment 1), modulations of the LSPC effect have been observed in the presence of smaller mean compatibility effects in prior studies (e.g., three-way interaction in Experiment 1 of Bugg et al. (2021), with mean compatibility effects around 60 ms). Second, the difference in the LSPC effect between the horizontal condition (23 ms) and vertical condition (20 ms) was negligible in Experiment 2. Both the frequentist, $F(1, 94) = 0.06$, $p = .815$, $\eta_p^2 < .01$, and Bayesian ($BF_{01} = 4.92$) analyses indicated that it is unlikely that there was a difference. If there was a hint of a difference favoring the horizontal (or vertical) condition, it would be more of a concern that an advantage was being obscured by the relatively lower difficulty of the task used in Experiment 2. Third, in an exploratory analysis, we did not find evidence that a difference between the horizontal and vertical condition was obscured by the overall smaller compatibility effects in Experiment 2. Specifically, when restricting our analyses to participants with the top 50% of compatibility effects (mean compatibility effect = 158 ms), the interaction between PC and trial type remained significant, $F(1, 46) = 13.24$, $p < .001$, $\eta_p^2 = .22$, and the three-way interaction between axis, PC, and trial type remained nonsignificant, $F(1, 46) = 0.12$, $p = .731$, $\eta_p^2 < .01$. Nonetheless, future studies might revisit the question addressed by Experiment 2 after identifying stimuli that (a) hold constant the number of distractor arrows in the gaze path across the different combinations of stimulus orientation and axis, and (b) yield equivalent compatibility effects to those observed in Weidler et al. and Experiment 1, as such studies would more directly rule out a difficulty explanation.

[4] We thank an anonymous review for raising this question.

## Limitations and future directions

The gaze path account implies that processing of the distractor dimension is an important factor in producing large compatibility and LSPC effects. One limitation of the present study is that we tested this account (and the horizontal precedence account) by manipulating axis and stimulus orientation selectively within a flanker task. Other paradigms may necessitate alternative approaches to encourage processing of the distractor dimension. For example, color (target) and word (distractor) are integrated in a traditional color-word Stroop task, and thus it may be that manipulating axis would not have any effect on the magnitude of compatibility or LSPC effects in that task. More generally there is a need to test both accounts outside the flanker task. It is possible that a horizontal advantage would be more likely to appear in a task that requires processing of location, providing support for the horizontal precedence account. This could be examined by using a task in which location is the task-relevant dimension, such as a Simon or a spatial Stroop task (see Pickel et al., 2019, for a discussion of increased use of location contexts with tasks that produce spatial conflict).

While our conceptualization of the gaze path account, and consequently the design of our experiments, focused on testing the role of conflict from the distractor arrows in the gaze path, it is also important to consider how our design choices affected processing of the central target arrow.[5] Consider the combinations of stimulus orientation and axes in Experiment 1 and Weidler et al. (2022). In the case of vertically oriented flanker stimuli in left and right locations along a horizontal axis (Experiment 1) and horizontally oriented flanker stimuli at upper and lower locations along a vertical axis (Weidler et al., 2022), in addition to the reduced distractor processing anticipated by the gaze path account, target processing may have been facilitated. The target was positioned directly in the center of the *x*- or *y*-axis from the fixation cross. This could have contributed to the reduced compatibility effects, and reduced LSPC effects in these conditions. In contrast, in the comparison conditions (vertically oriented flanker stimuli at upper and lower locations along a vertical axis [Experiment 1] and horizontally oriented flanker stimuli in left and right locations along a horizontal axis [Weidler et al., 2022]) where distractor processing was amplified according to the gaze path account, target processing may also have been interfered with and this could have contributed to the larger compatibility effects, and larger LSPC effects in these conditions. In Experiment 2, the gaze path account anticipated an equivalent amount of distractor processing regardless of axis, and similarly one could suggest that target processing also should be equivalent. The key point is that processing of the distractor arrows as well as the target likely contributed to the observed pattern of results. However, regardless of the conceptualization (whether one focuses exclusively on distractor processing or on a combination of distractor/target processing), the predictions remain the same for the gaze path and horizontal precedence accounts, and accordingly so does interpretation of the current findings with respect to these accounts.

The findings of Experiments 1 and 2 are better supported by the gaze path account than the horizontal precedence account. However, a limitation of the current study is that with behavioral data, we can only assume where participants gazed during each trial. It is possible that participants' gaze did not follow a path from the center of the screen to the central target arrow in the way we proposed. It is also possible that participants did not shift their gaze and instead relied on covert shifts of attention to respond to the target on some trials. To address this limitation, future research should track participants' eyes while they complete the flanker task in the different stimulus orientation/axis conditions to determine whether the gaze path processes more of the distracting flankers (and/or the target) in select conditions as anticipated by the gaze path account.

## Conclusion

Weidler et al. (2022) found that LSPC effects were larger when using a horizontal axis condition, suggesting the horizontal axis may be special for learning about the relationships between location and conflict. However, the results of the current study demonstrated that this effect was specific to the horizontally oriented stimuli used in that study rather than a more general, horizontal advantage. Using vertically oriented stimuli in Experiment 1, we found that the advantage observed by Weidler et al. flipped, such that the compatibility effect and LSPC effect were larger in the vertical axis condition (i.e., there was a vertical advantage). Using stimuli that equated the conflict in the gaze path for both axis conditions in Experiment 2, we found that compatibility effects and LSPC effects were equivalent for vertical and horizontal axis conditions. Our findings show that compatibility effects and LSPC effects are not always larger when locations are presented on a horizontal axis—that is, left/right locations are not special. Rather, consistent with the gaze path account, these effects are larger when the gaze path between central fixation and the target traverses through more distractor arrows (as occurs when horizontally oriented stimuli are presented on the horizontal axis and vertically oriented stimuli are presented on the vertical axis). Future research should aim to understand whether other design features that encourage participants to attend to the distractor dimension lead to stronger evidence for reactive control both in location-specific and other context-specific paradigms.

[5] We thank an anonymous reviewer for raising this possibility.

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