Reply

Psychological Science
2018, Vol. 29(9) 1558–1564

DOI: 10.1177/0956797618794131
www.psychologicalscience.org/PS
SAGE

A Comprehensive Meta-Analysis of Spatial Interference From Linguistic Cues: Beyond Petrova et al. (2018)

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Received 8/16/17; Revision accepted 7/13/18

Estes, Verges, and Barsalou (2008) demonstrated a *spatial interference effect*, in which linguistic cues with implicit spatial associations (e.g., "bird") hindered identification of an unrelated visual stimulus (e.g., "X") at the implied location (e.g., at the top of a display).[1] This effect, though counterintuitive, fits within a broader literature of visuospatial interference from linguistic cues (e.g., Bergen, Lindsay, Matlock, & Narayanan, 2007; Gozli, Chasteen, & Pratt, 2013; Richardson, Spivey, Barsalou, & McRae, 2003; Verges & Duffy, 2009). Most researchers explain spatial interference in terms of *perceptual simulation* (Barsalou, 1999): The linguistic cue evokes a subconscious mental image of the denoted object or event in its associated location, thereby visually masking (i.e., perceptually competing with) the target stimulus and delaying its identification. Recent alternative accounts have attributed spatial interference to more holistic event simulations (Ostarek & Vigliocco, 2017) or to conflicting semantic and spatial codes (Amer, Gozli, & Pratt, 2017; Estes, Verges, & Adelman, 2015).

Estes et al. (2008) demonstrated spatial interference three times across three experiments. Those experiments shared many common features: They all included cue words with spatial associations (e.g., "hat"), visual targets that were unrelated to the cue word ("X" or "O"), brief delays between the cue word and the visual target (300 ms or less), and a task in which the target ("X" or "O") had to be identified. The studies were conducted in English, which may be important, given that spatial interference is an effect of language on attention. Estes et al.'s first two experiments additionally included a context word to provide a spatial reference frame for the cue word (e.g., "cowboy hat"), whereas the third experiment presented the cue word alone (e.g., "hat"). Despite minor methodological differences in the delay between cue and target presentation and in the presence or absence of a context word, all three experiments demonstrated significant spatial interference.

Petrova et al. (2018) question the reliability of the spatial interference effect when the cue word is presented in isolation. That is, they contest the spatial interference in the third experiment of Estes et al. (2008). Notably, they do not contest Estes et al.'s two demonstrations of spatial interference when the cue word was preceded by a single context word. Petrova et al. reported a series of experiments that varied in similarity to those of Estes et al.'s Experiment 3, successfully replicating the spatial interference effect only once. They also meta-analyzed their results together with those of a select few experiments from the prior literature. Although the overall effect in their meta-analysis was significant ($N = 15$, $Z = 2.54$, $p = .011$; see their Fig. 1), Petrova et al. nonetheless concluded that the spatial interference effect is unreliable.

We disagree with Petrova et al.'s conclusion because (a) several of their experiments were conducted under conditions in which spatial interference is not theoretically expected, (b) their selective meta-analysis excluded many significant demonstrations of the effect, and (c) the overall effect in their meta-analysis was significant nevertheless. Petrova et al. revealed that such spatial cuing can additionally reveal a Simon effect, which occurs when the locations of the target stimulus and response key interact to affect responding. In the Supplemental Material available online for this Reply, however, we explain why the spatial interference effect cannot be understood as a Simon effect. Here, we report

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a comprehensive meta-analysis of the spatial interference effect (N = 37) that was conducted to test the overall reliability of the effect and to identify moderators that may reveal or conceal the effect (Braver, Thoemmes, & Rosenthal, 2014).[2]

Funneled Moderator Analysis

Following Estes et al.'s (2008) method in their original demonstrations of the spatial interference effect (described above), we sampled experiments in which (a) the linguistic cues were single words (e.g., "bird"), pairs of words (e.g., "cowboy hat"), or minimal sentences (e.g., "The glass fell"), referring to objects or actions across multiple categories (e.g., animals, clothing, household objects); (b) the visual targets were abstract and unrelated to the linguistic cues (e.g., "X" or "O," "■" or "●"); and (c) the task was to identify the visual target (not simply detect its presence). Individual experiments that included multiple tests of the hypothesis (e.g., with different instructions) were treated as separate tests. We excluded conditions that were specifically intended to eliminate spatial interference (e.g., the masked condition of Estes et al., 2008, Experiment 2). On the basis of these criteria, we obtained a final sample that consisted of 37 tests of the spatial interference effect, shown in Table 1. These tests are distributed across six published articles and three unpublished studies by five independent research groups. We report raw effect sizes (response times in milliseconds). For comparison, the classic semantic-priming effect is about 26 ms (Hutchison et al., 2013). See the Supplemental Material for more detailed methods and results, along with further assessments of replicability and robustness, in addition to further consideration of Petrova et al.'s studies.

Many of the 37 tests were conducted under conditions that differed from those used by Estes et al. (2008) in important ways. We therefore funneled our analysis by progressively applying identified moderators of the effect (Lipsey & Wilson, 2001) until the final analyses included only studies that closely resembled those of Estes et al. (2008). Our presumed moderators were guided by *grounded cognition*, which explains conceptual processing in terms of perception, action, and introspection (Barsalou, 2008). Researchers of grounded cognition argue that semantic representations include spatial information (e.g., Lebois, Wilson-Mendenhall, & Barsalou, 2015) and that semantic representations are activated dynamically in a task-dependent manner during conceptual processing (Barsalou, 2008, 2016; Connell & Lynott, 2014; Yee & Thompson-Schill, 2016). The identified moderators therefore focused on temporal dynamics and task factors that affect the extent of semantic processing (see Fig. 1).

First we consider temporal dynamics. Some tests of spatial interference used a long stimulus onset asynchrony (SOA; the delay between cue and target onsets), whereas Estes et al. (2008) specifically used short SOAs. This is important because semantic representations are activated early during conceptual processing (Moseley, Pulvermüller, & Shtyrov, 2013). At short SOAs, a perceptual simulation rapidly activated by the linguistic cue (e.g., "bird") in its associated location (top of the screen) perceptually competes with identifying the target ("X"), producing *interference*. With longer SOAs, however, the perceptual simulation dissipates, leaving visual attention in the cued location without perceptual competition. Consequently, at long SOAs (i.e., > 400 ms), *facilitation* may occur instead of interference (Gozli et al., 2013). Thus long SOAs, as Petrova et al. used in several of their studies, were not theoretically expected to exhibit spatial interference. Indeed, a simple linear correlation across the 37 tests of the effect (see Fig. 2a) reveals that spatial interference dissipates as SOA increases, Pearson $r = -.42$, 95% confidence interval (CI) = [−.65, −.11], $p = .011$, Spearman $\rho = -.46$, 95% CI = [−.68, −.16], $p = .004$. Figure 2b further shows that the 28 tests with short SOAs (i.e., ≤ 400 ms)[3] exhibited significant spatial interference (M = 8 ms, 95% CI = [6, 10], $p < .001$), whereas the 9 tests with long SOAs instead exhibited modest but significant spatial facilitation (M = −3 ms, 95% CI = [−6, −0.2], $p = .037$). Thus, as expected, SOA moderates the spatial interference effect.

Next, we consider task factors that affect semantic processing. Given that semantic processing is necessary for activating spatial representations (Lebois et al., 2015), lack of semantic processing should eliminate spatial interference. Reading can occur with little or no semantic processing, and the depth of semantic activation involved in reading varies across languages (Katz & Frost, 1992; Schmalz, Marinus, Coltheart, & Castles, 2015). Although not anticipated by Estes et al. (2008), our meta-analysis thus reveals a second apparent moderator of spatial interference: *orthographic depth*.

In orthographically "deep" languages such as English, the same letter or string of letters may have different pronunciations in different words (e.g., "t<u>ough</u>" and "th<u>ough</u>"), and hence word reading in deep languages requires semantic processing (Katz & Frost, 1992; Schmalz et al., 2015). In "shallow" languages such as Italian and German, in contrast, a given letter tends to be pronounced consistently across different words. Consequently, shallow languages "allow bypassing the semantic system" (Peressotti & Job, 2003, p. 180), and under some circumstances (Tabossi & Laghi, 1992), words can be read "with little or no reliance on semantic information" (Bates, Burani, D'Amico, & Barca, 2001, p. 986; see also Buchanan & Besner, 1993; Burani,

Table 1. Tests of the Spatial Interference Effect

Article and study	Condition	*N*	Language	SOA (ms)	Semantic context	Mean RT for congruent trials (ms)	Mean RT for incongruent trials (ms)	Effect size (ms)
Bergen, Lindsay, Matlock, & Narayanan (2007)								
Study 1	—	63	English	200	Yes	577	534	43*
Study 2	—	59	English	200	Yes	538	507	31*
Study 3	—	59	English	200	Yes	524	534	−10
Study 4	—	64	English	200	Yes	595	584	11
Estes, Verges, & Barsalou (2008)								
Exp. 1	—	18	English	300	Yes	534	497	37***
Exp. 2	Unmasked	26	English	150	Yes	492	418	74***
Exp. 3	—	27	English	150	No	494	462	32***
Verges & Duffy (2009)								
Study 1	Words	25	English	150	No	503	480	23*
Study 2	Nouns	48	English	150	No	565	518	47***
Study 2	Verbs	48	English	150	No	569	510	59***
Gozli, Chasteen, & Pratt (2013)								
Study 3	Short SOA	26	English	200–400	No	473	463	10**
Study 3	Long SOA	27	English	800–1,200	No	449	447	2
Study 4	Short SOA	40	English	200–400	No	630	623	7*
Study 4	Long SOA	40	English	800–1,200	No	498	504	−7*
Study 6	Short SOA	25	English	200–400	No	687	665	22*
Study 6	Long SOA	25	English	800–1,200	No	503	519	−16**
Petrova et al. (2013), Study 1	—	24	Italian	200	No	471	472	−1
Estes, Verges, & Adelman (2015)								
Study 3	—	52	English	150	No	543	507	36***
Study 4	—	39	English	150	No	541	510	31***
Renkewitz & Muller (2015), Study 1	—	22	German	300	Yes	499	500	0
Estes (2016), Study 1	—	116	Italian	150	No	530	528	3
Petrova et al. (2018)								
Exp. 1	150 delay	39	Italian	300	No	490	491	−1
Exp. 1	450 delay	39	Italian	600	No	498	499	−1
Exp. 1	900 delay	39	Italian	1,050	No	498	499	−1
Exp. 2	150 delay	39	Italian	300	No	585	587	−1
Exp. 2	450 delay	39	Italian	600	No	569	561	8
Exp. 2	900 delay	39	Italian	1,050	No	567	565	2
Exp. 3	150 delay	20	Italian	300	No	533	532	0
Exp. 3	450 delay	20	Italian	600	No	526	533	−7
Exp. 3	900 delay	20	Italian	1,050	No	519	522	−3
Exp. 4	—	18	Italian	200	No	480	480	0
Exp. 5	—	20	Italian	150	No	494	490	4
Exp. 6	—	24	Italian	150	No	523	522	2
Exp. 7	—	25	Italian	150	No	526	517	9*
Exp. 8	Biased	20	Italian	150	No	552	565	−13
Exp. 8	Neutral	20	Italian	150	No	528	525	3
Exp. 9	—	40	English	150	No	684	686	−2

Note: Stimulus onset asynchrony (SOA) is the delay between cue and target onsets. Semantic context refers to whether the linguistic cue was given within a brief sentence or word pair ("yes") or was a single word ("no"). Congruent and incongruent trials are those in which the visual target appeared, respectively, in the location associated with the cue word (e.g., "bird" → target at top) or in the opposite location (e.g., "bird" → target at bottom). Effect sizes were calculated by subtracting response times (RTs) for incongruent trials from RTs for congruent trials. Positive effect sizes indicate interference.
*$p < .05$. **$p < .01$. ***$p < .001$.

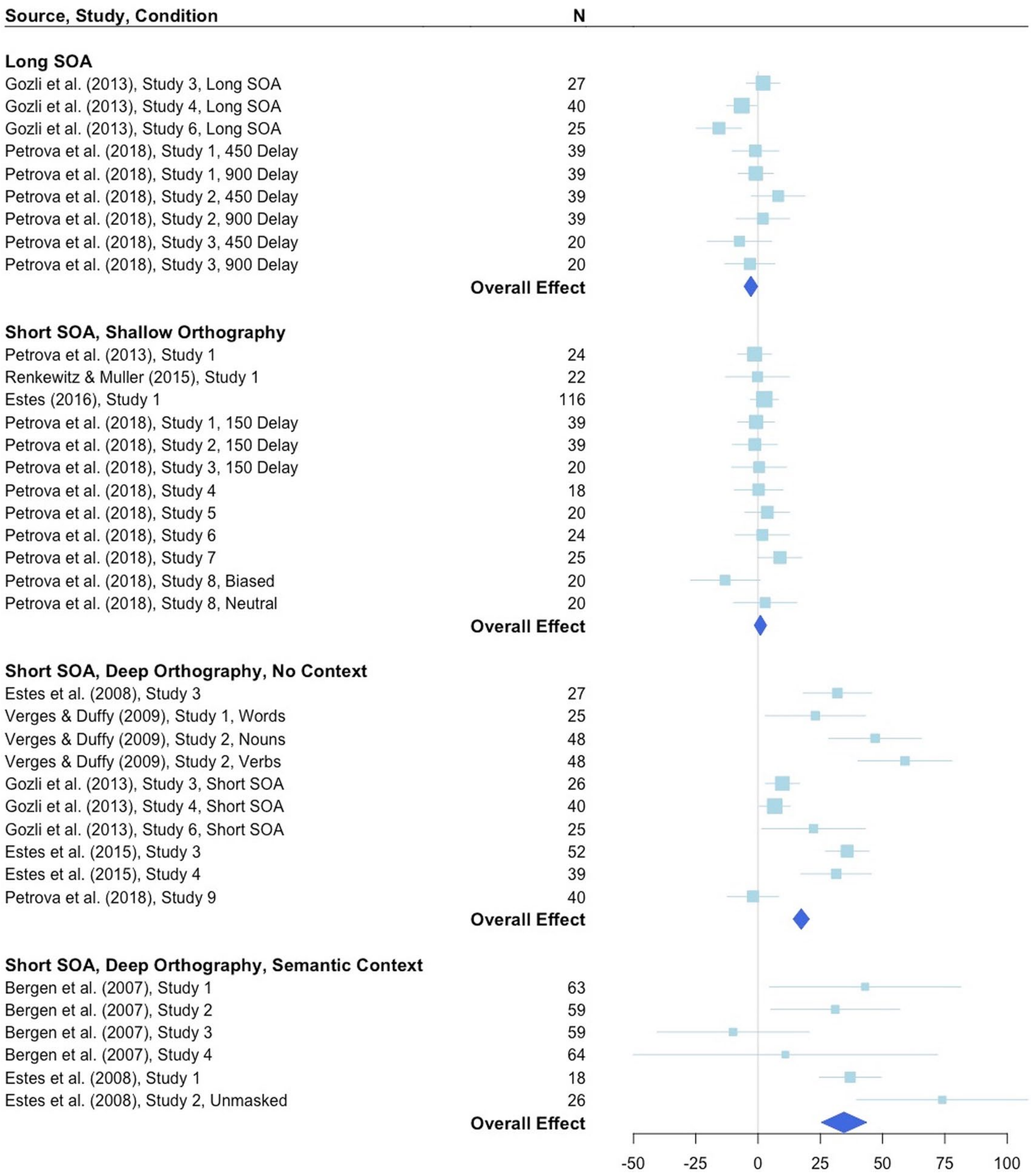

Fig. 1. Mean effect size of each of the 37 tests of the spatial interference hypothesis (far-right column), with 95% confidence intervals (error bars). The tests are grouped by stimulus onset asynchrony (SOA; short: ≤ 400 ms, long: > 400 ms), orthography (shallow: Italian or German, deep: English), and semantic context (present, absent). SOA is the delay between cue and target onsets. In Petrova et al.'s study, the conditions labeled "150 delay," "450 delay," and "900 delay" respectively used 300-ms, 600-ms, and 1,050-ms SOAs. The overall effect size for each group of tests is shown below that group's individual effect sizes.

Arduino, & Barca, 2007). Indeed, a connectionist model that includes no semantic system can nonetheless read Italian words with 98% accuracy (Pagliuca & Monaghan, 2010). Additionally, semantic factors such as imageability have more robust effects on reading in English (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004)

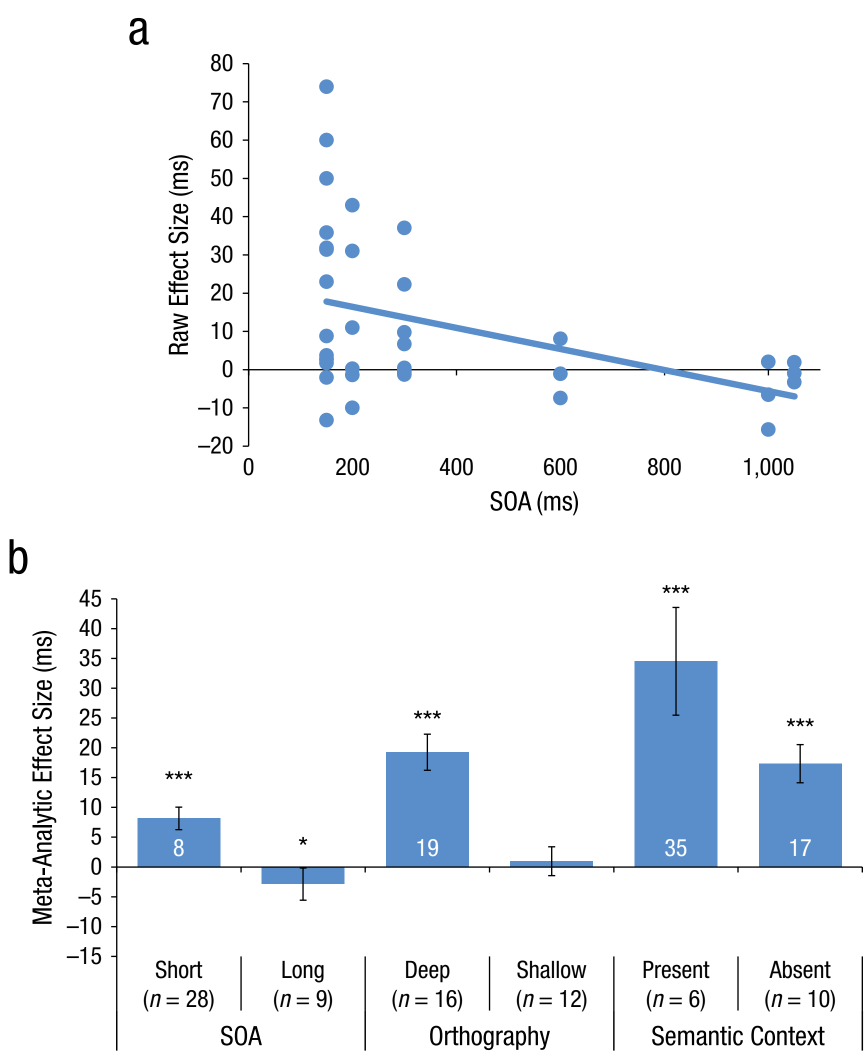

Fig. 2. Raw effect sizes for the 37 tests of the spatial interference hypothesis (a) and meta-analytic effect sizes for the same tests grouped by stimulus onset asynchrony (SOA), orthography, and semantic context (b). The scatterplot (a; with best-fitting regression line) shows the mean effect size for each test as a function of SOA. The graph (b) shows results from the funneled moderator analysis. SOAs were either short (≤ 400 ms) or long (> 400 ms), orthographies were either deep (English) or shallow (Italian or German), and the spatial cue either appeared in the context of a brief sentence or word pair (present) or was a single word (absent). Error bars represent 95% confidence intervals. Asterisks indicate effect sizes significantly different from zero (*$p < .05$, ***$p < .001$).

than in Italian (Bates et al., 2001), and semantic priming is more robust in English than in Italian (Tabossi & Laghi, 1992). Thus, given that spatial interference requires semantic processing, spatial interference is more likely in deep languages (e.g., English) than in shallow ones (e.g., Italian, German). In fact, our moderator analysis revealed that 13 of the 16 tests (81%) in English with short SOAs exhibited significant interference, with the overall effect size being moderate (19 ms, 95% CI = [16, 22], $p < .001$). In contrast, of the 12 tests in Italian or German with short SOAs, there was no spatial interference ($p = .44$; see Fig. 2b). Thus, orthographic depth appears to moderate the spatial interference effect via semantic processing. Given its post hoc nature, however, this observation warrants further investigation.

Finally, given that semantic processing activates spatial representations (Lebois et al, 2015), enhanced semantic processing should accentuate spatial interference. One factor that enhances semantic processing is context: Richer semantic contexts should more strongly evoke visuospatial representations (Wilson-Mendenhall, Simmons, Martin, & Barsalou, 2013) and hence should elicit greater spatial interference than sparse contexts (Lebois et al., 2015). Of the 16 tests in English with short SOAs, 6 presented the cues in the context of brief sentences (e.g., "The glass fell") or word pairs (e.g., "cowboy hat"), whereas 10 presented the cue words in isolation (e.g., "bird"). Notably, 9 of the 10 tests (90%) with no semantic context exhibited significant interference, and the overall effect size was moderate (17 ms, 95% CI = [14, 21], $p < .001$), indicating that semantic context is not necessary for spatial interference (see Fig. 2b). However, spatial interference was twice as large among the 6 tests with semantic context (35 ms, 95% CI = [25, 44], $p < .001$), reaching the level of classic semantic-priming effects (26 ms; Hutchison et al., 2013). This conclusion must be interpreted cautiously for several reasons: (a) The sample of effects is small, (b) the variance within and between these six effects is large (see Fig. 1), and (c) this moderation by semantic context was significant in a fixed-effects meta-analysis model but not in a random-effects model, suggesting insufficient power to generalize beyond existing studies. Thus, the spatial interference effect is significant without semantic context (in English with short SOAs), and although the effect tends to be larger with semantic context, further research is needed to establish this additional finding more conclusively.

Conclusions

Visuospatial interference from linguistic cues has been demonstrated many times, and the present meta-analysis confirms its reliability. Here, we have shown that spatial interference is moderated by temporal dynamics and semantic processing. Studies that do not evoke semantic processing of the linguistic cues (e.g., in orthographically shallow languages), or that test for visuospatial interference after the semantic representation has dissipated (i.e., at long SOAs), do not exhibit spatial interference. However, among studies that are similar to those of Estes et al. (2008)—in English with short SOAs—the effect is moderately large. Moreover, spatial interference may be accentuated by semantic contexts that evoke stronger perceptual simulations, further demonstrating its semantic basis. In conclusion, the spatial interference effect occurs reliably with semantic processing and varies systematically with temporal and linguistic constraints.

Action Editor

D. Stephen Lindsay served as action editor for this article.

Author Contributions

Z. Estes primarily developed the empirical contribution of this article, and L. W. Barsalou primarily developed the theoretical contribution, both with input from the other. Z. Estes analyzed the data and drafted the manuscript. L. W. Barsalou revised the manuscript. Both authors contributed to the figures. Both authors approved the final version of the manuscript for submission.

Acknowledgments

We sincerely thank Davood Gozli and Francesca Peressotti for providing their data for meta-analyses.

Declaration of Conflicting Interests

The author(s) declared that they had no conflicts of interest with respect to the authorship or the publication of this article.

Funding

Z. Estes gratefully acknowledges the generous support of the Invernizzi Center for Research on Innovation, Organization, Strategy and Entrepreneurship (ICRIOS) at Bocconi University.

Supplemental Material

Additional supporting information can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797618794131

Open Practices

This Reply reports a meta-analysis of studies previously conducted by various researchers. Thus, the materials and data are not ours to share in open access format. However, all summary data necessary to replicate our meta-analyses are available in Table 1. Moreover, we conducted our analyses via the freely available macros by Wilson (2006). Thus, all data and software necessary for replicating all analyses reported in this article are open access. The design and analysis plans for this meta-analysis were not preregistered.

Notes

1. This effect corresponds to what Petrova et al. termed "location-cue congruency, or LCC, effect" (p. 1195). We instead use the term "spatial interference" for consistency with the prior literature.
2. Because of publication bias, results of meta-analyses should be interpreted with caution.
3. We adopted the 400-ms cutoff for short SOAs established by Gozli et al. (2013), which is consistent with much classic research showing that attention (e.g., Posner & Snyder, 1975) and language (e.g., Neely, 1977) processing tend to change qualitatively around 300 ms to 400 ms after stimulus presentation.

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