Atten Percept Psychophys (2013) 75:1137–1147
DOI 10.3758/s13414-013-0477-2

Paying attention to attention: evidence for an attentional contribution to the size congruity effect

Evan F. Risko · Erin A. Maloney · Jonathan A. Fugelsang

Published online: 25 May 2013

Abstract Understanding the mechanisms supporting our comprehension of magnitude information represents a key goal in cognitive psychology. A major phenomenon employed in the pursuit of this goal has been the physical size congruity effect—namely, the observation that comparing the relative numerical sizes of two numbers is influenced by their relative physical sizes. The standard account of the physical size congruity effect attributes it to the automatic influence of the comparison of irrelevant physical magnitudes on numerical judgments. Here we develop an alternative account of this effect on the basis of the operation of attention in the typical size congruity display and the temporal dynamics of number comparison. We also provide a test of a number of predictions derived from this alternative account by combining a physical size congruity manipulation with a manipulation designed to alter the operation of attention within the typical size congruity display (i.e., a manipulation of the relative onsets of the digits). This test provides evidence consistent with an attentional contribution to the size congruity effect. Implications for our understanding of magnitude and the interactions between attention and magnitude are discussed.

Keywords Space-based attention · Automaticity · Numerical cognition

E. F. Risko (✉)
Psychology Department, University of Memphis,
Memphis, TN 38152, USA
e-mail: efrisko@memphis.edu

E. A. Maloney
University of Chicago, Chicago, IL, USA

J. A. Fugelsang
University of Waterloo, Waterloo, Ontario, Canada

Our ability to understand magnitude information is the bedrock upon which numerical cognition is built. Indeed, McCloskey (1992) argued that the ability to select the larger of two quantities is *the* criterion for our understanding of number. One of the most commonly studied phenomena in the effort to understand how the human brain processes magnitude information is the *size congruity effect* (also commonly referred to as the numerical Stroop effect; Algom, Dekel, & Pansky, 1996; Ansari, Fugelsang, Dhital, & Venkatraman, 2006; Besner & Coltheart, 1979; Borgmann, Fugelsang, Ansari, & Besner, 2011; Cohen Kadosh et al., 2007; Fitousi & Algom, 2006; Pansky & Algom, 1999; Santens & Verguts, 2011; Schwarz & Heinze, 1998; Schwarz & Ischebeck, 2003). In tasks used to study the physical size congruity effect, participants are typically presented with two simultaneously presented digits and are asked to identify the numerically larger of the two. Critically, the simultaneously presented digits differ not only in their numerical magnitudes, but also in their physical magnitudes. Thus, some trials are congruent, in which the numerically larger stimulus is also physically larger (e.g., 2 7), and others are incongruent, in which the numerically larger stimulus is physically smaller (e.g., 2 7). The resulting size congruity effect refers to the observation that participants are faster (and more accurate) on congruent than on incongruent trials, despite the fact that the physical size of the digits is irrelevant to the numerical magnitude judgment. This pattern has been widely interpreted as reflecting interference between the processing of numerical magnitude and the automatic comparison of irrelevant physical magnitudes. Although this interpretation of the size congruity effect has considerable intuitive appeal, which has likely contributed to its widespread acceptance, in the present investigation we develop an alternative, attentional account of the physical size congruity effect and provide empirical support for at least an attentional contribution to the said effect.

An attentional account of the size congruity effect

The attentional account of the physical size congruity effect developed here is based on two ideas. The first is that the structure of the display used in a typical physical size congruity experiment, via an attentional capture effect (Kiss & Eimer, 2011; Proulx, 2010; Proulx & Egeth, 2008; Proulx & Green, 2011), leads to an asymmetry in the temporal order with which the digits are processed. The second idea is that in a number comparison task, an asymmetry in the temporal order with which the digits are processed produces a temporal congruity effect that takes the same form as that putatively produced by the automatic comparison of irrelevant physical magnitudes (Schwarz & Stein, 1998). We unpack these two ideas below. It should be clear at this point that the size congruity effect that is the focus of the present investigation deals with the influence of irrelevant physical size on numerical magnitude judgments. The converse effect (i.e., the influence of irrelevant numerical magnitude on physical size judgments), although interesting in its own right, is not addressed here. We will refer to the physical size congruity effect as the *size congruity effect* throughout.

Visual attention and size

In a typical experiment in which the size congruity effect is used to study magnitude processing, participants are asked to decide which of two digits is numerically larger. The display consists of two digits, typically side by side, and their relative physical sizes are manipulated. Critically, research has suggested that this disparity in physical size could generate a disparity in the ability of the two digits to draw attention. For example, in a visual search task, Proulx and Egeth (2008) demonstrated that the slope of the RT × Set Size function is reduced when the target is physically larger than the distractors, suggesting that the physically larger stimulus captures attention (see also Kiss & Eimer, 2011; Proulx, 2010; Proulx & Green, 2011). This effect occurred despite size being irrelevant to the task. Thus, attention can be influenced by the relative size of a stimulus. Returning to the display in a typical size congruity experiment (i.e., physically small and large stimuli placed side by side), this size-based attentional capture effect suggests that attention would be shifted initially toward the physically larger digit. Given attention's facilitative effect on stimulus processing (e.g., Carrasco, 2006; Posner, Nissen, & Ogden, 1978; Risko, Stolz, & Besner, 2010; Spence & Parise, 2010), this attentional capture effect would confer a kind of temporal advantage in processing to the physically larger digit relative to the physically smaller digit (i.e., the physically larger digit would begin being processed before the physically smaller one). Taken together, this interaction between visual attention and physical size supports the first tenet of the attentional account—specifically, that the structure of the display used in a typical size congruity experiment, via its influence on attention, leads to an asymmetry in the temporal order with which the digits are processed.

The temporal congruity effect

In the previous section, we introduced the notion that the typical display in a size congruity experiment could create an asymmetry in the temporal order with which the digits are processed. Critically, this notion has important implications for the mechanism underlying the size congruity effect. This occurs because the influence of that asymmetry on performance could mimic the putative effect of the automatic comparison of irrelevant physical magnitudes. Schwarz and Stein (1998) provided evidence for this idea in an investigation of the temporal dynamics of digit comparison. In this series of experiments, they presented participants with two numbers that differed in numerical magnitude but not in physical magnitude and asked the participants to identify the numerically larger digit (i.e., a typical number comparison task). Importantly, they manipulated the temporal order (ranging from 0- to 210-ms interstimulus intervals) with which the two digits were presented. For the present purposes, the critical point was that under "select larger" instructions, participants responded faster when the digit that was presented first was the numerically larger digit than when the digit presented first was the numerically smaller digit. Thus, in the display "8–2," responses were faster when the "8" rather than the "2" was presented first. Schwarz and Stein referred to this effect as a *temporal congruity effect*. Simply put, when the digit that corresponded with the response was presented first, responses were faster than when that digit was presented second.

The existence of a temporal congruity effect is important in the present context because it demonstrates that a manipulation that influences the temporal order with which the digits are processed will, in and of itself, produce a form of congruity effect. In other words, in a typical size congruity experiment, if the numerically larger digit is processed first, responses will then be faster than if the numerically smaller digit is processed first. Critically, through the influence of physical size on attention, this is just what would happen given the typical display in a size congruity experiment. On congruent trials (e.g., 2 7), the numerically larger digit should be processed first because it is the physically larger digit, and, as described above, the physically larger digit should be more effective at capturing attention than the physically smaller digit. The same logic leads to the conclusion that on incongruent trials (e.g., 2 7), the numerically smaller digit should be processed first. Thus, on congruent trials the numerically larger digit is processed first, and on incongruent trials the numerically smaller digit is processed first, which matches the conditions that Schwarz and Stein (1998) demonstrated produce a temporal congruity effect (i.e., participants should be faster in the former than in the latter condition). This suggests that the size congruity effect could be a product (in full or in part) of an attention-based temporal congruity effect rather than the automatic comparison of physical magnitudes. We provide a strong test of this account here.

Before describing the present experiment, it is important to note that the attentional account has difficulty explaining one important result: The size congruity effect is observed when a digit is presented in isolation (Santens & Verguts, 2011; Schwarz & Heinze, 1998; Schwarz & Ischebeck, 2003; Tzelgov, Meyer, & Henik, 1992). For example, Schwarz and Heinze had participants compare a single digit to a fixed standard (a value of 5) and manipulated the digit's physical size. Participants responded faster when the digit's numerical and physical sizes (relative to the standard) were congruent than when the digit's numerical and physical sizes were incongruent. In other words, they found a size congruity effect. Assuming that this effect is the same as the one generated when the digits are presented simultaneously, which should not necessarily be assumed (see Maloney, Risko, Preston, Ansari, & Fugelsang, 2010), this result would be difficult for an attentional account to explain. This is because there would be no opportunity for a size-based attentional capture effect to produce a bias in the temporal order with which the digits would be processed, and hence no attention-based temporal congruity effect. Interestingly, the magnitude of the size congruity effect in studies that have used the single-digit design appears, on visual inspection, to be much smaller than the size congruity effect observed using the simultaneous-digit design. For example, in Santens and Verguts's study, the size congruity effect was about 40 ms using a simultaneous-digit design, but less than 20 ms using a single-digit design (see also Schwarz & Heinze, 1998; Schwarz & Ischebeck, 2003, for similar magnitude size congruity effects in single-digit conditions). This pattern of results raises the possibility that the size congruity effect in the simultaneous condition could be the result of two mechanisms—the automatic comparison of irrelevant magnitudes, along with an attentional contribution.

Present investigation

In the present investigation, participants were presented with two digits side by side that differed in both numerical and physical size, and they were instructed to select the numerically larger digit. Recall that according to the attentional account, the size congruity effect is the result of an asymmetry in the temporal order with which the digits are processed. Thus, a critical prediction of the attentional account is that a manipulation that produces an offsetting asymmetry should reduce the magnitude of the size congruity effect. In the present investigation, we achieved this by combining the physical size manipulation with a manipulation of the actual physical onset times of the two digits (as in Schwarz & Stein, 1998). We used three onset conditions: (1) *physically smaller first*: the physically smaller digit appeared 100 ms before the physically larger digit; (2) *physically larger first*: the physically larger digit appeared 100 ms before the physically smaller digit; and (3) simultaneous: both digits appeared at the same time. According to the attentional account, when the physically smaller digit is presented first, the magnitude of the size congruity effect should be reduced (or eliminated) relative to when the two digits are presented at the same time. This is because in the *physically smaller first* condition, the processing order induced by the physical onsets (i.e., physically smaller digit, then physically larger digit) opposes the processing order induced by attention (i.e., physically larger digit, then physically smaller digit), and as a result should reduce any contribution of an attention-based temporal congruity effect.

The attentional account also makes an interesting prediction regarding the *physically larger first* condition. Note that when the physically larger digit is presented first, the processing orders induced by the physical onsets and by attention correspond with one another. Thus, one might argue that the size congruity effect in the *physically larger first* condition should increase in magnitude. Although this result would not be inconsistent with an attentional account, a more constraining prediction can be derived on the basis of the assumption that presenting the stimuli one digit at a time would reduce (or eliminate) the influence of the structure of the display on attention. This is because the physical onsets themselves will influence the distribution of attention. For example, when the physically larger digit is presented first, its onset will attract attention, and as a result, the attention-grabbing nature of its relative size would be rendered ineffectual (i.e., the onset will have already drawn attention to the physically larger digit before the relative size would have an opportunity to do the same; see Risko, Lanthier, & Besner, 2011, for application of a similar logic in a different domain). According to this argument, the size congruity effect in the *physically larger first* condition should be equivalent to the size congruity effect in the *simultaneous* condition, or at least the latter difference should be smaller in magnitude than that observed between the *physically smaller first* and *simultaneous* conditions.

The last prediction tested here addresses one of the underlying assumptions of the attentional account—specifically, that in the displays used in a typical (i.e., "select larger") size congruity experiment, the physically larger digit captures attention. In the present investigation, participants' eyes were monitored during performance of the numerical comparison task. The attentional account does not require that individuals overtly attend (i.e., move their eyes) to the physically larger digit. Indeed, this would be unlikely, given that the physically smaller stimulus is more difficult to resolve, and hence more likely to attract eye movements. However, we can use characteristics of the eye movements that are made to the digits to provide clues regarding the extents to which they captured attention. Specifically, if the physically larger digit captures attention first, the time between display onset and the initiation of the first saccade toward a digit (i.e., the saccadic initiation time) should be shorter when the saccade is made toward the physically larger digit than when the saccade is made toward the physically smaller digit. This prediction is based on work investigating oculomotor capture (e.g., Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999), which has demonstrated that erroneous saccades to salient distractors are typically initiated more quickly than correct saccades to targets. The explanation is that the salient distractor initially captures covert attention and, on some trials, a saccade follows. On the remaining trials (i.e., when no saccade is made to the distractor), covert attention is redirected to the target, and a saccade is executed. Critically, when comparing the two saccades, the one made to the salient distractor is faster (i.e., it follows the initial shift of attention) than the one made to the target (i.e., it follows the redirection of covert attention from the distractor to the target). Thus, the relative speeds with which saccades are initiated can act as a proxy for the capture of attention. On the basis of this logic, in the present context if the saccades made to the physically larger stimulus were systematically faster than those made to the physically smaller stimulus, this would support the hypothesis that the physically larger stimulus is initially capturing attention.

Thus, three different predictions are tested here: (1) Presenting the physically smaller digit first will reduce the magnitude of the size congruity effect, (2) presenting the physically larger digit first will not influence the magnitude of this effect (or at least will influence it less than presenting the physically smaller digit first), and (3) saccades to the physically larger digit in the simultaneous condition will be faster than saccades to the physically smaller digit.

Method

Participants

Forty two students from Arizona State University participated for either class credit or a payment of $5.

Apparatus

Experiment Builder experimental software (SR Research Ltd.) controlled the timing and presentation of stimuli and logged responses and the response times (RTs). A responsePixx button box was used for collecting manual responses. An SR Research EyeLink 1000 desk-mounted eyetracking system recording at 1000 Hz was used to record eye movements. The stimuli were presented to participants on a 19-in. monitor with its resolution set at 1,024 × 768. The stimuli, along with eye position, were also presented to the experimenter on a second monitor so that real-time feedback could be given about system accuracy.

Stimuli

A fixation cross (+) and the digits, presented to the left and right of fixation, were presented in white on a black background. The digits 1, 2, 7, and 8 were used and were presented in Courier font. The use of these four digits followed recent work by Santens and Verguts (2011). When the digit was small, 16-point font was used, and when the digit was large, 64-point font was used. Each digit pair (i.e., all combinations of digits, sides, onsets, and sizes) was presented equally often. Thus, six digit pairs were possible: [1, 2], [1, 7], [1, 8], [2, 7], [2, 8], and [7, 8], which were presented equal numbers of times with the lower digit on the left and on the right, equal numbers of times with the physically smaller digit on the left and on the right, and equal numbers of times in the *smaller first*, *simultaneous*, and *larger first* conditions. Together, this resulted in 72 unique displays, and each was presented four times, for a total of 288 trials (144 in each of two blocks, with trial order randomly selected within blocks).

Procedure

Participants went through a nine-point calibration of the eyetracker to begin. Another nine-point calibration was administrated at the halfway point, and also as needed throughout the experiment. Participants were instructed that on each trial two digits would be presented and that they were to hit the button on the same side as the *numerically* larger digit. Each trial began with the presentation of the fixation cross for 500 ms. In the *physically smaller first* and *physically larger first* conditions, the physically smaller/larger stimulus was presented for 100 ms, followed by the physically larger/smaller stimulus. In the *simultaneous-onset* condition, on half the trials the two digits appeared at the offset of the fixation (early onset), and on the other half they appeared 100 ms after the offset of the fixation (late onset). This was done so as not to confound onset with condition. Returning to the structure of the stimulus set, this meant that of the four repetitions of each unique display in the simultaneous condition (described in the Stimuli section), two were early onset and two were late onset. The digits remained on the screen until a response was made. Calculation of RTs began at the onset of the second digit when they were successive, at the onset of the two digits in the late-onset condition, and 100 ms after the onset of the two digits in the early-onset condition (i.e., the timer began at the same point in the trial across conditions).

Results

The first 32 trials in the first block were considered practice and not analyzed (leaving 112 of the 144 trials in the first block considered as experimental trials). Only correct trials were used in the RT analysis. Outliers in RTs (2.1%) were defined as those greater than 2.5 standard deviations above or below the participant's cell mean and were removed. A "cell" in this instance refers to the 4 (onset: physically smaller first vs. simultaneous early onset vs. simultaneous late onset vs. physically larger first) × 2 (size congruity: congruent vs. incongruent) design. Preliminary analysis showed no difference in the size congruity effects across the early- and late-onset *simultaneous* conditions. As such, we collapsed across onsets in that condition.[1] A 3 (onset: physically smaller first vs. simultaneous vs. physically larger first) × 2 (size congruity: congruent vs. incongruent) analysis of variance (ANOVA) was performed on the mean RT and percentage-of-error data. Effect size estimates (partial eta squared) are provided. All of the ANOVAs were repeated measures ANOVAs. When interpreting the percentage error data, it should be kept in mind that very few errors were made in the task (i.e., most cell means were 0). The results are presented in Fig. 1.

In RTs, we found no main effect of onset, but there was a significant effect of size congruity, $F(1, 41) = 107.00$, $MSE =$ 1,234.03, $p < .05$, $\eta_p^2 = .72$, and an interaction between onset and size congruity, $F(2, 82) = 21.86$, $MSE = 604.72$, $p < .05$, $\eta_p^2 = .35$. Critically, the magnitude of the size congruity effect (incongruent – congruent) was significantly smaller in the *physically smaller first* condition (18 ms) than in both the *simultaneous* condition (54 ms), $t(41) = 5.71$, $SED = 6.37$, $p < .05$, and the *physically larger first* condition (66 ms), $t(41) = 5.45$, $SED = 8.83$, $p < .05$. No difference was apparent between the *simultaneous* condition and the *physically larger first* condition, $t(41) = 1.60$, $SED = 7.36$, $p > .05$. Furthermore, the magnitude of the reduction in the size congruity effect on the *physically smaller first* trials relative to the *simultaneous* trials (36 ms) was significantly larger than the increase in the size congruity effect on the *physically larger first* trials relative

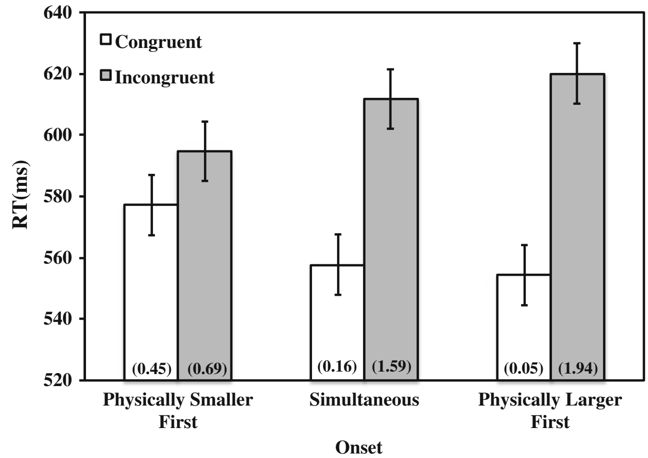

Fig. 1 Mean response times (RTs, in milliseconds) and percentages of error (in parentheses) as a function of onset and size congruity, with 95% confidence intervals (Masson & Loftus, 2003)

to the *simultaneous* trials (12 ms), $t(41) = 2.32$, $SED = 10.55$, $p < .05$. All of the size congruity effects were significant, $t(41) = 3.06$, $p < .05$; $t(41) = 10.00$, $p < .05$; and $t(41) = 8.94$, $p < .05$, for the *smaller first*, *simultaneous*, and *larger first* conditions, respectively.

In errors, no main effect of onset emerged, but we did find a significant effect of size congruity, $F(1, 41) = 21.42$, $MSE =$ 4.13, $p < .05$, $\eta_p^2 = .34$, and an interaction between onset and size congruity, $F(2, 82) = 6.70$, $MSE = 2.26$, $p < .05$, $\eta_p^2 = .14$. Consistent with the RT analyses, the magnitude of the size congruity effect was significantly smaller in the *physically smaller first* condition (0.24%) than in both the *simultaneous* condition (1.43%), $t(41) = 3.34$, $SED = 0.49$, $p < .05$, and the *physically larger first* condition (1.89%), $t(41) = 2.49$, $SED =$ 0.48, $p < .05$. We observed no difference between the *simultaneous* condition and the *physically larger first* condition, $t(41) = 1.10$, $SED = 0.42$, $p > .05$. A parallel set of comparisons using a Wilcoxon signed ranks test (nonparametric) yielded the same pattern (physically smaller first vs. simultaneous, $Z = 1.98$, $p < .05$; physically smaller first vs. physically larger first, $Z = 2.97$, $p < .05$; simultaneous vs. physically larger first, $Z = 1.01$, $p = .3$).

Distance effects

Numerous researchers have demonstrated that performance in number comparison tasks is influenced by the numeric distance between the to-be-compared digits (Moyer & Landauer, 1967). As such, we conducted a 4 (distance: 1, 5, 6, 7) × 3 (onset: physically smaller first vs. simultaneous vs. physically larger first) × 2 (size congruity: congruent vs. incongruent) repeated measures ANOVA on RTs and percentages of error.

With respect to the influence of numeric distance on RT, we observed a main effect, $F(3, 123) = 115.06$, $MSE =$

[1] When only the late-onset simultaneous condition was included in the reported analyzes (i.e., the *simultaneous* condition wherein RT was timed from stimulus onset), the results were qualitatively similar. The major difference between this analysis and the one reported in the text is a main effect of onset, such that responses were slower overall in the *simultaneous* condition. This was likely a result of the fact that in the nonsimultaneous conditions, participants got a 100-ms head start processing one of the digits.

3,201.49, $p < .05$, $\eta_p^2 = .74$, such that RTs became shorter as distance increased (615, 618, 565, and 540 ms, respectively). In addition, distance interacted with size congruity, $F(3, 123) = 2.95$, $MSE = 2{,}179.11$, $p < .05$, $\eta_p^2 = .07$, such that the influence of the latter decreased as the former increased (59, 45, 36, and 41 ms, respectively). Critically, distance did not interact with onset, $F(6, 246) = 1.53$, $MSE = 1{,}825.19$, $p = .17$, $\eta_p^2 = .04$, nor did it modulate the Size Congruity × Onset interaction, $F(6, 246) = 0.58$, $MSE = 1{,}639.51$, $p = .75$, $\eta_p^2 = .01$.

In percentages of error, the pattern mirrored that in the RTs, in that we found a main effect of distance, $F(3, 123) = 11.60$, $MSE = 13.29$, $p < .05$, $\eta_p^2 = .22$, such that individuals' accuracy increased as distance increased (1.5%, 1.4%, 0.19%, and 0.05% errors, respectively); distance interacted with size congruity, $F(3, 123) = 5.63$, $MSE = 13.50$, $p < .05$, $\eta_p^2 = .12$, such that the influence of the latter decreased as the former increased (2.4%, 1.5%, 0.3%, and 0.1% errors, respectively); and critically, distance did not modulate the Size Congruity × Onset interaction, $F(6, 246) = 1.03$, $MSE = 9.20$, $p = .40$, $\eta_p^2 = .02$. A parallel analysis using Friedman's test (nonparametric) yielded the same pattern. There was a significant distance effect, $\chi^2(3) = 29.93$, $p < .05$; the size congruity effect was modulated by distance, $\chi^2(3) = 8.05$, $p < .05$; and the Size Congruity × Onset interaction, using the smaller-first versus larger-first difference as a function of onset, was not modulated by distance, $\chi^2(3) = 2.4$, $p = .489$.

End digits

In numerical comparison tasks that include sequential comparisons, the first digit presented can, in some cases, determine the response independent of the presentation of the second digit (Schwarz & Stein, 1998; Sekuler, Rubin, & Armstrong, 1971). For example, in the present design, when one of the digits at either extreme (i.e., 1, 8) was presented, participants could in principle respond without seeing the second stimulus. Such circumstances have been shown to influence performance in sequential numerical comparison tasks (Schwarz & Stein, 1998; Sekuler et al., 1971). In order to investigate the influence of whether or not the initial digit on nonsimultaneous trials influenced performance, we conducted a post-hoc analysis separating trials beginning with the digits 1, 8 (i.e., end digits) and 2, 7 (i.e., non-end digits) into separate conditions. A 2 (end digit first) × 2 (onset) × 2 (congruity) within-subjects ANOVA was performed on both RTs and percentages of error.

In RTs, a main effect of end digit first emerged, $F(1, 41) = 118.03$, $MSE = 1{,}189.38$, $p < .05$, $\eta_p^2 = .74$, such that trials on which the first digit was 1 or 8 (566 ms) were faster than trials on which the first digit was a 2 or 7 (607 ms). We found no interaction between end digit first and congruity, $F(1, 41) = 0.41$, $MSE = 1{,}174.31$, $p < .05$, $\eta_p^2 = .01$, but there was a marginally significant interaction between end digit first and onset, $F(1, 41) = 3.91$, $MSE = 1{,}237.00$, $p = .06$, $\eta_p^2 = .09$. Lastly, we observed a significant three-way interaction between end digit first, onset, and congruity, $F(1, 41) = 5.16$, $MSE = 1{,}495.72$, $p < .05$, $\eta_p^2 = .11$, such that the Onset × Congruity interaction (size congruity effect on *smaller first* trials < size congruity effect on *larger first* trials) was larger when the first digit was a 2 or 7 (67 ms) than when the first digit was a 1 or 8 (30 ms). Critically, the Onset × Congruity interaction was significant both when the first digit was a 2 or a 7, $F(1, 41) = 32.34$, $MSE = 1{,}470.40$, $p < .05$, $\eta_p^2 = .44$, and when the first digit was a 1 or an 8, $F(1, 41) = 5.52$, $MSE = 1{,}592.97$, $p < .05$, $\eta_p^2 = .12$.

In percentages of error, we also found a main effect of end digit first, $F(1, 41) = 26.75$, $MSE = 3.96$, $p < .05$, $\eta_p^2 = .39$, such that trials on which the first digit was 1 or 8 (0.2%) were more accurate than trials on which the first digit was 2 or 7 (1.3%). In addition, a significant End Digit First × Congruity interaction was apparent, $F(1, 41) = 11.24$, $MSE = 3.95$, $p < .05$, $\eta_p^2 = .21$, such that the effect of congruity was larger when the first digit was 2 or 7 (1.8%) than when the first digit was 1 or 8 (0.33%). The End Digit First × Onset interaction, as in RTs, was marginal, $F(1, 41) = 3.26$, $MSE = 4.66$, $p = .08$, $\eta_p^2 = .07$, and a significant interaction emerged between end digit first, onset, and congruity, $F(1, 41) = 8.50$, $MSE = 5.03$, $p < .05$, $\eta_p^2 = .17$, such that the Onset × Congruity interaction was larger when the first digit was 2 or 7 (3.1%) than when the first digit was 1 or 8 (0.21%). Note that the small size of the latter effect likely results from a floor effect (i.e., there was a small congruity effect when the first digit was a 1 or an 8; see above). A parallel set of comparisons using a Wilcoxon signed ranks test (nonparametric) yielded the same pattern (fewer errors when 1 or 8 appeared first than when 2 or 7 appeared first, $Z = 4.07$, $p < .05$; congruity effect smaller when 1 or 8 appeared first than when 2 or 7 appeared first, $Z = 3.03$, $p < .05$; and a smaller Onset × Congruity interaction when 1 or 8 appeared first than when 2 or 7 appeared first, $Z = 2.56$, $p < .05$).

Eye movements

The saccadic initiation times (time between display onset and the initiation of the first saccade toward a digit) were compared for the first eye movement toward either the physically larger or physically smaller digit on *simultaneous* trials. In order to determine whether a saccade was made toward a digit, interest areas were drawn around each digit (these interest areas were the same size for all digits). As in the RT and error analyses, practice trials were removed. In addition, trials on which participants did not begin the trial in the fixation interest area or on which the saccadic initiation time was less than 50 ms were removed. Three participants were excluded from the analysis because they had at least one empty cell. The final analysis consisted of 1,630 individual eye movements, with an average of 40 per participant and a range between 2 and 76. The low number per participant reflects the restriction to the *simultaneous* condition and the fact that eye movements were not required in order to complete the task. A one-factor repeated measures ANOVA with two levels (physically larger vs. physically smaller) was conducted. We found a significant effect of size, $F(1, 38) = 13.76$, $MSE = 2{,}073.31$, $p < .05$, $\eta_p^2 = .26$, such that eye movements toward the physically larger stimulus (277 ms) were faster than eye movements toward the physically smaller digit (315 ms).

To provide a further test of the notion that "fast" eye movements were directed toward the physically larger stimulus, we divided the saccadic initiation times into four bins (quartiles) from fastest to slowest for each participant and calculated the proportion of saccades directed toward the physically larger stimulus in each bin. This analysis provided an assessment of the likelihood of making a saccade to the physically larger digit as a function of saccadic initiation time. Three participants were excluded from the analysis because they had at least one empty cell. A one-factor repeated measures ANOVA with four levels was conducted. We found a significant effect of bin, $F(3, 114) = 9.57$, $MSE = 0.04$, $p < .05$, $\eta_p^2 = .20$, such that the proportion of saccades that went to the physically larger digit increased as saccadic initiation time decreased. A parallel analysis using a Friedman (nonparametric) test also revealed a significant effect of bin, $\chi^2(2, N = 39) = 27.8$, $p < .01$. In other words, the faster the saccade was initiated, the more likely it was to go to the physically larger digit.

As is evident from Fig. 2, overall, participants were more likely to move their eyes to the smaller digit. This is consistent with the fact that the physically smaller digit would be harder to resolve without an eye movement than was the physically larger digit. Note that this is not inconsistent with the attentional account, given that covert shifts of attention can occur independently of an overt shift of attention (i.e., an eye movement), and the analysis above is consistent with covert attention initially shifting to the physically larger digit.

Discussion

In the introduction, we derived three predictions from the attentional account of the size congruity effect: (1) presenting the physically smaller digit first will reduce the magnitude of the size congruity effect, (2) presenting the physically larger digit first will not influence the magnitude of the size congruity effect (or at least will influence it less than presenting the physically smaller digit first), and (3) in the *simultaneous* condition, saccades to the physically larger digit will be faster than saccades to the physically smaller digit. All three predictions were supported. When the physically smaller digit was presented before the physically larger digit, the magnitude of the size congruity effect was significantly reduced relative to when the digits were presented simultaneously. In other words, when the digits were presented in a manner that would counteract the influence of the attentional bias toward the physically larger stimulus, the size congruity effect was reduced. The fact that the size congruity effect was reduced, but not eliminated, is also important, as it suggests that the attention-based account likely explains a portion (albeit a potentially large

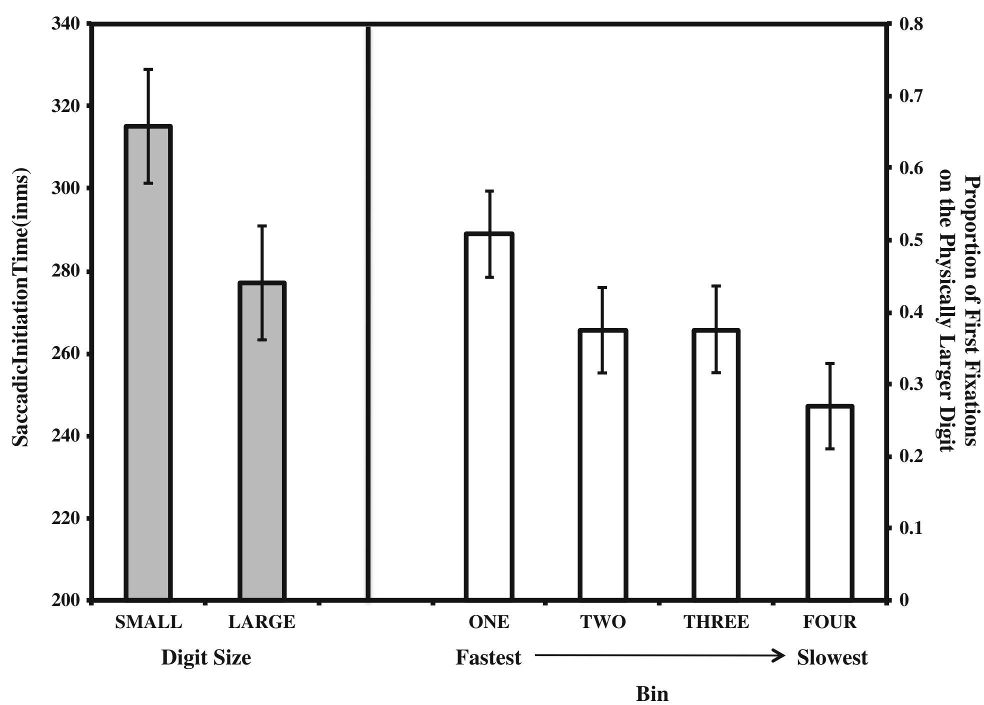

Fig. 2 Left panel: Saccadic initiation times (in milliseconds) to the physically larger and physically smaller digits. Right panel: Proportions of first fixations made to the physically larger digit as a function of saccadic initiation times, grouped into four bins (one, two, three, and four) from fastest to slowest, and with 95% confidence intervals (Masson & Loftus, 2003)

portion) of the physical size congruity effect, but not all of it. This issue is discussed further below. Consistent with the second prediction, we observed limited influence of presenting the larger stimulus first, relative to the *simultaneous* condition: The size congruity effect in the *physically larger first* condition was statistically equivalent to the effect in the *simultaneous* condition. Critically, the reduction in the *physically smaller first* condition was also statistically larger than the increase in the *physically larger first* condition (both relative to the simultaneous condition), providing further support for the asymmetrical influence of the onset manipulation as a function of whether the smaller or larger stimulus was the first to be attended. As we noted in the introduction, this pattern is consistent with the notion that the onset of the larger digit attracts attention on some trials, and as a result, the impact of the larger digit's tendency to attract attention is weakened (i.e., attention is already at the location of the larger digit). Finally, the analysis of eye movements also provided converging evidence consistent with the attentional account. Specifically, on *simultaneous* trials, first saccades toward the physically larger digit were significantly faster than first saccades toward the physically smaller stimulus. Furthermore, the faster the saccadic initiation time, the more likely the eye movement was to be headed toward the physically larger stimulus. Both of these results are consistent with the notion that the physically larger stimulus initially captures covert attention when the display is presented. Thus, all three predictions were supported.

Taken together, the present results provide a strong case for an attentional contribution to the physical size congruity effect, and in so doing present a novel and important challenge to the standard automatic-comparison-of-irrelevant-magnitudes account as an explanation for the entire physical size congruity effect. This account has rarely been challenged. However, this fact appears to be more a result of the lack of viable alternatives than of this account defeating them (see Risko, Blais, Stolz, & Besner, 2008a, b, for a similar observation in the case of strategic effects in selective attention tasks). In the following section, we discuss challenges to an attentional account and explore the idea that the typical size congruity effect is a product of both the automatic comparison of irrelevant magnitudes and an attention-based temporal congruity effect.

Challenges to an attentional account

Given the support for the standard account of the size congruity effect, it is important at present to address some potential challenges to the proposed attentional account. One nonattentional explanation of the present results is that two independent effects exist—a temporal congruity effect and a size congruity effect—and, on trials in which the smaller digit appeared first, these effects were simply put in opposition, thus partially canceling each other out. For example, this could potentially explain the reduction in the size congruity effect in the *physically smaller first* condition. The problem with this alternative account is that it predicts that on *physically larger first* trials, the size congruity effect should have increased in magnitude as much as it decreased in the *physically smaller first* condition. That is, the temporal congruity effect (resulting from the different onsets) and size congruity effect (resulting from the automatic comparison of irrelevant magnitudes) should have added together, leading to a larger overall effect. The fact that this was not the case is difficult to explain if one were to favor this alternative account. In a similar vein, an account in which attention (somehow) modulates the automatic comparison of irrelevant magnitudes would fail (at least without further explication of the potential mechanism). Finally, the nonattentional alternative account would leave unexplained the evidence for orienting toward the physically larger stimulus (or at least have to argue that this orienting has no influence on number comparison).

Another potential issue with the attentional account is that the size congruity effect can be observed with the standard "select larger" instructions and the less used "select smaller" instructions (Santens & Verguts, 2011). This is important because the temporal congruity effect (Schwarz & Stein, 1998) reverses under the "select smaller" instruction. That is, under "select smaller" instructions, participants responded faster when the digit presented first is the numerically smaller digit than when the digit presented first is the numerically larger digit. This observation is problematic for an attentional account if the physically larger digit is always the first to be attended. This is because the attentional bias under "select smaller" instructions would still lead individuals to process the physically larger stimulus first, and hence there would be no temporal congruity effect (i.e., for a temporal congruity effect to emerge under the "select smaller" instructions, the physically smaller digit would have to be processed first). As we noted above, this challenge is problematic if the attentional bias toward physically larger stimuli is fixed. However, this might not be the case. Rather, attentional capture by relative size could represent a form of contingent capture (Folk, Remington, & Johnston, 1992). Contingent capture represents a form of attentional capture that is dependent on the task set of the individual (e.g., "if I am looking for an onset, then an onset will capture my attention"). Evidence for this idea has been provided recently by Kiss and Eimer (2011), who demonstrated that when participants are looking for a small stimulus, attention is more likely to be captured by a small singleton (i.e., a physically small stimulus amongst medium-sized stimuli), and when participants are looking for a large stimulus, attention is more likely to be captured by a large singleton (i.e., a physically large stimulus amongst medium sized stimuli; Kiss & Eimer, 2011). Thus, it is possible that the instruction to "select larger" or "select smaller" is what drives the form of the attentional bias, rather than a more basic aspect of the stimulus. According to these results, under the "select smaller" instructions the physically smaller digit would capture attention, and as a result produce a temporal congruity effect. A direct test of this idea in the specific context of numbers and number comparison has not been attempted, to our knowledge. It is important to note that whereas the contingent-capture account provides a mechanism through which an attention-based account could explain a size congruity effect under the "select smaller" instructions, it does so while at the same time making the prediction that under such instructions, evidence for the reverse of the attention bias observed here (i.e., the eye movement analysis) should be found. In other words, if the posited direction of the attentional bias is influenced by instructions, then this should be demonstrable independent of the magnitude of the size congruity effect itself.

It is also important to note that even in the attentional account posited here, there exists a kind of "comparison" of irrelevant magnitude/size occurring, in the sense that relative magnitude/size contributes to an attention shift. Nonetheless, according to the attentional account, the size congruity effect results (at least partly) from the attentional shift induced by that preshift comparison, and not from the preshift comparison competing with the comparison of the relevant magnitudes. The present data support such a conclusion. In addition, it is unclear whether the "comparison" that leads to the attention shift should be considered the same kind of comparison that leads to facilitation/interference on the automatic-comparison-of-irrelevant-magnitudes account. For example, according to saliency-based accounts, attentional selection represents the result of a competition between locations on the basis of their relative saliencies (which is determined by low-level properties of the stimulus; e.g., Itti & Koch, 2001), wherein the output of such a computation would be more akin to "attend here" than to "the right digit is larger." The latter would seem to be required to interfere with the computations made on the relevant dimension. That said, this issue deserves further investigation.

Another important result to consider in this light was reported by Goldfarb and Tzelgov (2005). Using a background image with built-in distance cues, Goldfarb and Tzelgov were able to manipulate the perceived size of the digits while keeping the physical size similar (i.e., if two digits are equal in physical size, but one is perceived as being farther away, it will also be perceived as larger). Critically they found a significant size congruity effect. This result suggests that the orienting of covert attention, hypothesized to be contributing to the size congruity effect, must be operating on the perceived size of the stimuli rather than on the actual size. Evidence consistent with this notion was provided earlier by Robertson and Kim (1999), who demonstrated, using displays similar to those of Goldfarb and Tzelgov, that object-based cueing effects (Egly, Driver, & Rafal, 1994) were modulated by the perceived size of the object, as opposed to the physical size of the object. Even stronger evidence for this notion was provided by Proulx and Green (2011), who demonstrated, also using visual illusions, that the size-based attentional capture effect reviewed above is based on perceived size rather than actual size. Thus, the attentional account can explain the Goldfarb and Tzelgov results.

The attentional account is also consistent with results demonstrating that the magnitude of the physical size congruity effect (i.e., irrelevant physical size influencing number comparison) is directly related to the discriminability of the physical size dimension (Fitousi & Algom, 2006; Pansky & Algom, 1999). Specifically, as the discriminability of the physical size dimension increases, the magnitude of the facilitation/interference from the irrelevant size dimension increases. This critical result is also consistent with the attentional account put forward here, in that increasing the difference between the physical sizes of the two digits would be expected to increase the likelihood of an attentional asymmetry emerging. For example, a large difference in saliency between two stimuli would be expected to lead to less competition for attention (i.e., a clearer "winner" will emerge; Itti & Koch, 2001).

A tale of two mechanisms

As was noted in the introduction, the attentional account of the size congruity effect has difficulty explaining the presence of a size congruity effect when a digit is presented in isolation (Santens & Verguts, 2011; Schwarz & Heinze, 1998; Schwarz & Ischebeck, 2003; Tzelgov et al., 1992), because in such a display there would be no opportunity for a size-based attentional capture effect to produce a bias in the temporal order with which the digits are processed. This is only an issue for the attentional account if we assume that the size congruity effects in the single-digit and two-simultaneous-digit variants are one and the same. Recent research has suggested that such an assumption should not be taken lightly. Maloney et al. (2010) demonstrated little correlation between the distance effects observed in the single-digit and two-simultaneous-digit variants of numeric comparison tasks. A further reason for skepticism is the fact that the size congruity effects in studies that have used the single-digit design appear to be much smaller than the size congruity effects observed using the simultaneous-digit design. Taken together, a parsimonious suggestion is that the size congruity effect in the simultaneous condition reflects two contributions—one from the automatic comparison of irrelevant magnitudes, and one from an attention-based temporal congruity effect. Consistent with this notion is the observation, in the present experiment, that a significant 18-ms size congruity effect remained, even with a 100-ms head start for the physically smaller stimulus. The magnitude of this leftover size congruity effect is similar to the magnitude of the size congruity effects in single-digit designs (Santens & Verguts, 2011; Schwarz & Heinze, 1998; Schwarz & Ischebeck, 2003), where the putative attentional contribution would be neutralized.

Attention and magnitude

Beyond the size congruity effect, the present investigation highlights the potential utility of investigating further interactions between attention and magnitude. To date, research investigating such interactions has been surprisingly sparse beyond, for example, numerical magnitude's association with space (Ashkenazi, Rubinsten, & Henik, 2009; Casarotti, Michielin, Zorzi, & Umiltà, 2007; Cohen Kadosh & Henik 2006; Fischer, Castel, Dodd, & Pratt, 2003; Ranzini, Dehaene, Piazza, & Hubbard, 2009; Ristic, Wright, & Kingstone 2006). The latter work has demonstrated that numerical magnitude can produce shifts in attention. For example, Fischer et al. demonstrated that small numbers produced a shift of covert attention to the left, and larger numbers produced a shift of covert attention to the right. Thus, magnitude clearly influences attention, and the present investigation at least suggests that attention can influence magnitude judgments. Nevertheless, a host of interesting questions exist concerning the interactions between attention and magnitude that remain unresolved. For example, one influential theory of magnitude representation posits a common code for ostensibly different types of magnitude (Bueti & Walsh, 2009; Walsh, 2003). Given this shared representation of magnitude, one might expect that attentional control settings (Folk et al., 1992) held to bias attention to one type of magnitude (e.g., numerical) could produce a bias to attend to similar dimensions of other types of magnitude (e.g., physical). For example, looking for larger numbers might bias individuals to attend to large objects, and looking for larger objects might bias one to attend to large numbers. Exploring the attentional consequences of shared magnitude representations represents one of many potential future directions in this area.

Conclusion

The size congruity effect reflects a benchmark phenomenon in the numerical cognition literature as a result of its role as an index of the automatic comparison of irrelevant physical magnitudes. We have developed an alternative mechanism to explain the size congruity effect on the basis of existing knowledge about attentional function (Kiss & Eimer, 2011; Proulx, 2010; Proulx & Egeth, 2008; Proulx & Green, 2011) and the temporal dynamics of number comparison (Schwarz & Stein, 1998). We provided the first tests of this mechanism and the first clear demonstration of an attentional contribution to the size congruity effect. As such, this new account (and the data supporting it) suggests that the dominant automatic-comparison-of-irrelevant-magnitudes theory is likely not a complete explanation of the size congruity effect. At present, a dual-mechanism account appears most plausible as an explanation of the typical size congruity effect. Beyond the size congruity effect, the present research highlights the potential value in investigating the relation between attention and various representations of magnitude, in particular, and other cognitive phenomena, in general.

References

Algom, D., Dekel, A., & Pansky, A. (1996). The perception of number from the separability of the stimulus: The Stroop effect revisited. *Memory & Cognition, 24,* 557–572.

Ansari, D., Fugelsang, J. A., Dhital, B., & Venkatraman, V. (2006). Dissociating response conflict from numerical magnitude processing in the brain: An event-related fMRI study. *NeuroImage, 32,* 799–805. doi:10.1016/j.neuroimage.2006.04.184

Ashkenazi, S., Rubinsten, O., & Henik, A. (2009). Attention, automaticity, and developmental dyscalculia. *Neuropsychology, 23,* 535–540.

Besner, D., & Coltheart, M. (1979). Ideographic and alphabetic processing in skilled reading of English. *Neuropsychologia, 17,* 467–472.

Borgmann, K., Fugelsang, J., Ansari, D., & Besner, D. (2011). Congruency proportion reveals asymmetric processing of irrelevant physical and numerical dimensions in the size congruity paradigm. *Canadian Journal of Experimental Psychology, 65,* 98–104. doi:10.1037/a0021145

Bueti, D., & Walsh, V. (2009). The parietal cortex and the representation of time, space, number and other magnitudes. *Philosophical Transactions of the Royal Society B, 364,* 1831–1840.

Carrasco, M. (2006). Covert attention increases contrast sensitivity: Psychophysical, neurophysiological, and neuroimaging studies. In S. Martinez-Conde, S. L. Macknik, L. M. Martinez, J.-M. Alonso, & P. U. Tse (Eds.), *Visual perception: Part I. Fundamentals of vision: Low- and mid- level processes in perception* (Progress in Brain Research, Vol. 155, pp. 33–70). Amsterdam, The Netherlands: Elsevier.

Casarotti, M., Michielin, M., Zorzi, M., & Umiltà, C. (2007). Temporal order judgment reveals how number magnitude affects visuospatial attention. *Cognition, 102,* 101–117. doi:10.1016/j.cognition.2006.09.001

Cohen Kadosh, R., Cohen Kadosh, K., Linden, D. E. J., Gevers, W., Berger, A., & Henik, A. (2007). The brain locus of interaction between number and size: A combined functional magnetic resonance imaging and event-related potential study. *Journal of Cognitive Neuroscience, 19,* 957–970. doi:10.1162/jocn.2007.19.6.957

Cohen Kadosh, R., & Henik, A. (2006). A common representation for semantic and physical properties. *Experimental Psychology, 53,* 87–94.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123,* 161–177. doi:10.1037/0096-3445.123.2.161

Fischer, M. H., Castel, A. D., Dodd, M. D., & Pratt, J. (2003). Perceiving numbers causes spatial shifts of attention. *Nature Neuroscience, 6,* 555–556.

Fitousi, D., & Algom, D. (2006). Size congruity effects with two-digit numbers: Expanding the number line? *Memory & Cognition, 34,* 445–457. doi:10.3758/BF03193421

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 1030–1044. doi:10.1037/0096-1523.18.4.1030

Goldfarb, L., & Tzelgov, J. (2005). Is size perception based on monocular distance cues computed automatically? *Psychonomic Bulletin & Review, 12,* 751–754.

Itti, L., & Koch, C. (2001). Computational modeling of visual attention. *Nature Reviews Neuroscience, 2,* 194–203. doi:10.1038/35058500

Kiss, M., & Eimer, M. (2011). Attentional capture by size singletons is determined by top-down search goals. *Psychophysiology, 48,* 784–787. doi:10.1111/j.1469-8986.2010.01145.x

Maloney, E. A., Risko, E. F., Preston, F., Ansari, D., & Fugelsang, J. (2010). Challenging the reliability and validity of cognitive measures: The case of the numerical distance effect. *Acta Psychologica, 134,* 154–161. doi:10.1016/j.actpsy.2010.01.006

Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology, 57,* 203–220. doi:10.1037/h0087426

McCloskey, M. (1992). Cognitive mechanisms in number processing: Evidence from acquired dyscalculia. *Cognition, 44,* 107–157.

Moyer, R. S., & Landauer, T. K. (1967). Time required for judgements of numerical inequality. *Nature, 215,* 1519–1520. doi:10.1038/2151519a0

Pansky, A., & Algom, D. (1999). Stroop and Garner effects in comparative judgment of numerals: The role of attention. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 39.

Posner, M. I., Nissen, M. J., & Ogden, W. C. (1978). Attended and unattended processing modes: The role of set for spatial location. In H. L. Pick Jr. & E. Saltzman (Eds.), *Modes of perceiving and processing information* (pp. 137–157). Hillsdale, NJ: Erlbaum.

Proulx, M. J. (2010). Size matters: Large objects capture attention in visual search. *PLoS ONE, 5,* e15293. doi:10.1371/journal.pone.0015293

Proulx, M. J., & Egeth, H. E. (2008). Biased competition and visual search: The role of luminance and size contrast. *Psychological Research, 72,* 106–113.

Proulx, M. J., & Green, M. (2011). Does apparent size capture attention in visual search? Evidence from the Muller-Lyer illusion. *Journal of Vision, 11*(13), 21. doi:10.1167/11.13.21. 1–6.

Ranzini, M., Dehaene, S., Piazza, M., & Hubbard, E. M. (2009). Neural mechanisms of attentional shifts due to irrelevant spatial and numerical cues. *Neuropsychologia, 47,* 2615–2624.

Risko, E. F., Blais, C., Stolz, J. A., & Besner, D. (2008a). Covert orienting: A compound-cue account of the proportion cued effect. *Psychonomic Bulletin & Review, 15,* 123–127. doi:10.3758/PBR.15.1.123

Risko, E. F., Blais, C., Stolz, J. A., & Besner, D. (2008b). Nonstrategic contributions to putatively strategic effects in selective attention tasks. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 1044–1052. doi:10.1037/0096-1523.34.4.1044

Risko, E. F., Lanthier, S. N., & Besner, D. (2011). Basic processes in reading: The effect of inter-letter spacing. *Journal of Experimental Psychology: Learning, Memory and Cognition, 37,* 1449–1457.

Risko, E. F., Stolz, J. A., & Besner, D. (2010). Spatial attention modulates crosstalk amongst features in visual word processing. *Attention, Perception, & Psychophysics, 72,* 989–998. doi:10.3758/APP.72.4.989

Ristic, J., Wright, A., & Kingstone, A. (2006). The number line effect reflects top-down control. *Psychonomic Bulletin & Review, 13,* 862–868. doi:10.3758/BF03194010

Robertson, L. C., & Kim, M. S. (1999). Effects of perceived space on spatial attention. *Psychological Science, 10*, 76–79.

Santens, S., & Verguts, T. (2011). The size congruity effect: Is bigger always more? *Cognition, 118,* 97–113.

Schwarz, W., & Heinze, H. J. (1998). On the interaction of numerical and size information in digit comparison: A behavioral and event-related potential study. *Neuropsychologia, 36,* 1167–1179.

Schwarz, W., & Ischebeck, A. (2003). On the relative speed account of number-size interference in comparative judgments of numerals. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 507–522. doi:10.1037/0096-1523.29.3.507

Schwarz, W., & Stein, F. (1998). On the temporal dynamics of digit comparison processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 1275–1293.

Sekuler, R., Rubin, E., & Armstrong, R. (1971). Processing numerical information: A choice time analysis. *Journal of Experimental Psychology, 90,* 75–80.

Spence, C., & Parise, C. (2010). Prior entry: A review. *Consciousness and Cognition, 19,* 364–379. doi:10.1016/j.concog.2009.12.001

Theeuwes, J., Kramer, A. F., Hahn, S., Irwin, D. E., & Zelinsky, G. J. (1999). Influence of attentional capture on oculomotor control. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1595–1608. doi:10.1037/0096-1523.25.6.1595

Tzelgov, J., Meyer, J., & Henik, A. (1992). Automatic and intentional processing of numerical information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 166–179. doi:10.1037/0278-7393.18.1.166

Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences, 7,* 483–488. doi:10.1016/j.tics.2003.09.002