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Choosing the Larger Versus Choosing the Smaller: Asymmetries in the Size Congruity Effect

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The size congruity effect (SiCE) shows that number and physical size interact as magnitudes. That is, response times are faster when number and size are congruent (e.g., 2 4) than when they are incongruent (e.g., 2 4). A shared representational system has been the most influential account for the SiCE. Recently, this account has been challenged by findings showing that the SiCE may be influenced by attention. The attentional contribution to the SiCE suggests that the effect is produced by an attention capture effect to the larger stimulus. Even though plausible, the attentional account overlooks 2 important factors in the study of magnitudes, namely, task (numerical vs. physical) and polarity of instructions (choose the larger vs. the smaller). We studied the influence of these factors using a size congruity task. Experiment 1 showed that the SiCE was modulated by task and instructions. In Experiment 2, we used a new set of numbers to examine a possible influence of the so-called end effect (i.e., responses to the smallest and to the largest numbers may not require number comparison). Experiment 2 successfully replicated the pattern of Experiment 1. We suggest that both feature saliency and long-term semantic processes modulate the SiCE.

Keywords: numbers, magnitude representation, attention, saliency

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An excellent illustration that different magnitudes, such as numbers and physical size, interact in the human cognitive system is provided by the extensively studied size congruity effect (SiCE; Besner & Coltheart, 1979; Henik & Tzelgov, 1982). In the SiCE, participants are asked to decide which number of a pair of numbers is numerically larger. Different numerical values are mapped with different physical sizes resulting in congruent (e.g., 2 6) and incongruent (e.g., 2 6) conditions. The SiCE is illustrated by faster (and more accurate) responses for the congruent than for the incongruent condition. This effect has been replicated several times and has been considered a powerful tool to address both the cognitive (Algom, Dekel, & Pansky, 1996; Cohen Kadosh & Henik, 2006; Schwarz & Ischebeck, 2003; Tzelgov, Meyer, & Henik, 1992) and the neural (Cohen Kadosh, Cohen Kadosh, Linden et al., 2007; Göbel, Johansen-Berg, Behrens, & Rushworth, 2004; Pinel, Piazza, Le Bihan, & Dehaene, 2004) basis of magnitude processing.

The SiCE was originally explained by the existence of a shared magnitude system. Recently, attention capture was added as an explanation for the effect (Risko, Maloney, & Fugelsang, 2013). The latter explanation is related to the definition of the target task (choose the larger vs. choose the smaller). We refer to the definition of the target task as the "polarity of instructions" throughout this manuscript. Surprisingly, our literature search found that SiCEs were measured disproportionately with "choose larger" than with "choose smaller" instructions. Is the SiCE modulated by attention capture? What is the influence of the polarity of instructions on the SICE? The current work aims to examine these issues.

The Shared Representation Account

Before we continue, we would like to present the original size congruity experiment. Henik and Tzelgov (1982) addressed the level of processing underlying numerical representation in the SiCE by asking participants to report the physical size of two numbers while ignoring the numerical value. They reasoned that if number value and physical size were processed in parallel, a task-irrelevant number should produce a reliable SiCE. More importantly, if numbers were processed at the semantic level, a distance effect should be observed even though numerical quantity was task-irrelevant. The distance effect is characterized by an increase in RTs when the distance between the two numbers is small (e.g., 2 4) as opposed when it is large (e.g., 2 7; Moyer & Landauer, 1967). Participants performed numerical and physical tasks in different sessions. As expected, both congruity and distance effects were found for the numerical and the physical tasks; strong evidence for the automatic and parallel processing of magnitudes.

A well-accepted interpretation of the SiCE is that both numerical and size information are mapped into an analogue magnitude representation (Henik & Tzelgov, 1982). Walsh (2003; see also Bueti & Walsh, 2010) extended this view in "a theory of magni-

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tude" (ATOM) to propose that different magnitudes (e.g., number, space, and time) are processed by a single representational mechanism. According to this proposal, different magnitudes share a common metric system that is available to subserve action. The single representational mechanism is only partially shared between magnitudes, as each dimension may be subject to domain-specific processes (Bueti & Walsh, 2010). We refer to this as the *shared representation account* throughout this manuscript. A number of electrophysiology and brain imaging studies support the existence of a shared magnitude system. For example, in an event-related potentials (ERPs) study, Schwarz and Heinze (1998) showed that interaction between numbers and physical size occurred at preresponse selection stages, as reflected by P300 activation consistent with stimulus categorization and evaluation. A reduction in the SiCE was observed following transcranial magnetic stimulation (TMS) to the right intraparietal sulcus (IPS) when both numerical and physical tasks were used (Cohen Kadosh, Cohen Kadosh, Schuhmann et al., 2007). As we will discuss later, converging evidence also suggests that interactions between magnitudes may also depend on the way each dimension is processed.

The Effects of Attention in the SiCE

Recently, Risko et al. (2013) challenged the shared representation account of the SiCE by proposing an alternative *attentional account*. The attentional account is grounded on two ideas. The first is that the differences in the physical size of the two numbers in the size congruity task produce an attention capture effect to the larger stimulus, leading to an asymmetry in the temporal order by which the target is processed. That is, the processing of the physically larger stimulus is prioritized due to this attention shift conferring a kind of temporal advantage to the larger stimulus. Second, in the number of comparison tasks, the temporal asymmetry by which each number is processed produces a temporal congruity effect (Schwarz & Stein, 1998). The temporal congruity effect refers to a reaction time (RT) advantage when the digit that corresponds with the response is presented first relative to when it is presented second. Risko and colleagues adapted the task used by Schwarz and Stein (1998) by presenting asynchronously two numbers differing in physical size. The participants' task was to report the larger number (i.e., the relevant dimension was numerical value). The authors hypothesized that if the SiCE was due to a temporal advantage for processing the larger stimulus, presenting the small stimulus first should overcome this temporal advantage, reducing the SiCE. Their results showed a reduction in the SiCE when the smaller digit was presented first. They interpreted these findings as strong support for the attentional account of the SiCE.

The possibility that the SiCE may be modulated by attention is of great relevance for understanding the processing of magnitudes. However, the study carried out by Risko et al. (2013) presents a number of methodological limitations and overlooks two fundamental factors that have been shown to influence magnitude processing in the context of the SiCE. The first factor is the definition of task (numerical vs. physical size). As we mentioned before, the interpretation that the SiCE reflects a common coding of magnitudes comes from studies showing that both dimensions (number and physical size) affect RTs when task-irrelevant (e.g., Henik & Tzelgov, 1982). Risko and colleagues did not include a physical task (i.e., which number is larger physically) in their study. Second, the proposal that attention plays a major role in the SiCE predicts that instructions should modulate the SiCE. When choosing the *larger* stimulus, the larger stimulus is the target. Therefore, attention goes to the same location of the target in congruent trials and to the opposite location of the target in incongruent trials. The difference in attention capture between congruent and incongruent trials was interpreted by Risko and colleagues to underlie the SiCE. In contrast, if Risko and colleagues would have asked participants to choose the smaller number, attention would still have been directed to the larger element first, producing slow RTs in congruent trials and faster RTs in incongruent trials. Therefore, the attentional account predicts a reversed congruity effect under *choose the smaller* condition. If attention capture is an important factor for the SiCE, the critical test for its effects is by manipulating the polarity of instructions.

In addition, it is also possible that the reduction in the SiCE reported by Risko et al. (2013) was produced by response-related factors. In their task, two numbers differing in physical size were presented asynchronously. Participants were always instructed to choose the larger number. Therefore, when the small number appeared first, the response needed to be supressed because it was not the target stimulus. The difference between target-first (larger first) as opposed to distractor first (smaller first) conditions may have reduced the SiCE. Again, a critical test for the processing advantage of the large stimulus would be to include a condition in which the target is the smaller stimulus.

The Present Study

The present experiment aims to examine the role of task and polarity of instructions in the SiCE by using the classical size congruity task. A survey of the literature raised the interesting observation that the SiCE has been studied disproportionately using "choose the larger" as opposed to "choose the smaller" instructions. We entered "size congruity effect" as keywords into the ISI Web of Knowledge search engine. Results indicated 117 reports. From these, we selected those that fulfilled the following methodological criteria: (a) reports using the size congruity task; (b) studies using symbolic numerical information; (c) simultaneous presentation of numbers; and (d) reporting results for adults. Surprisingly, from the 47 reports that matched these criteria (see reference list in online supplemental material), only five included the condition to "choose the smaller" (see supplementary materials). In three of these reports, the congruity effect was not analyzed as a function of polarity of instructions (Liu, Wang, Corbly, Zhang, & Joseph, 2006; Santens & Verguts, 2011; Turconi, Campbell, & Seron, 2006).

Tzelgov et al. (1992, Experiment 3) manipulated both the task (numerical and physical) and instructions. We have replotted their results (see Figure 1, panel A). In their experiment, participants were asked to report, in different blocks, the smaller or the larger numerical value (or the physical size). For the purpose of the present report, we replotted the first block of trials only to avoid presenting results that could be affected by task order (see Henik & Tzelgov, 1982, regarding the effects of order in the SiCE). Their findings can be summarized as follows: First, for the numerical task, the SiCE is larger under instructions of choose the larger number as opposed to choose the smaller number; second, this instruction asymmetry in the SiCE does not hold for the physical

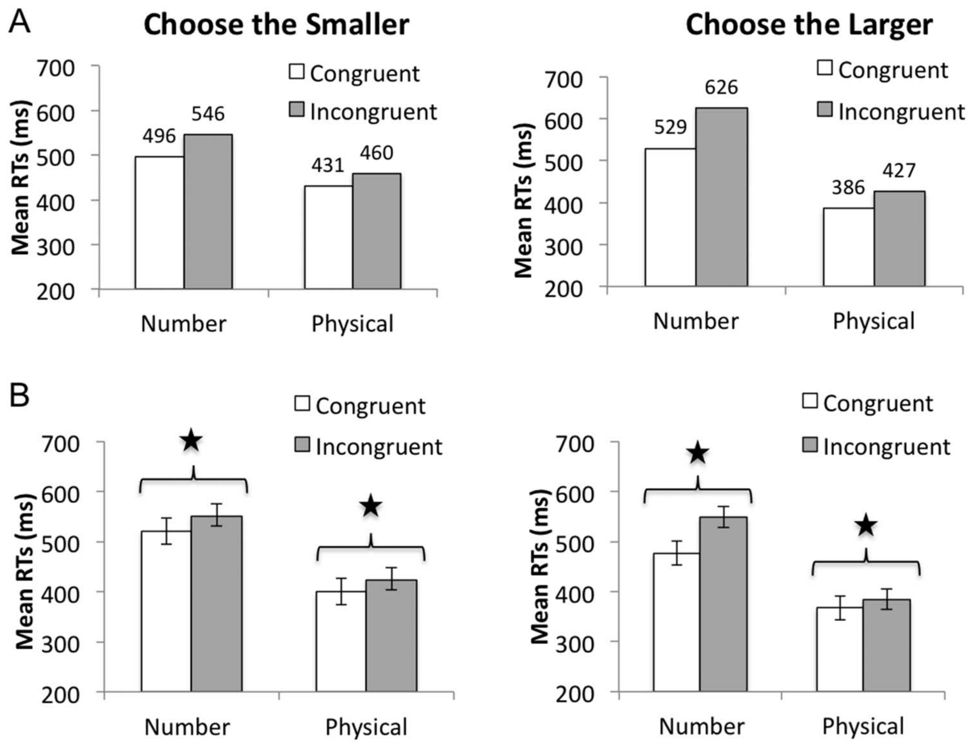

Figure 1. Panel A show results taken from Tzelgov et al. (1992) reproduced with permission of the publisher and the authors. Mean RTs are plotted for "choose the smaller" (left graph) and "choose the larger" (right graph) as a function of task (number and physical size) and congruity. Panel B and panel C show results for Experiment 1 and Experiment 2, respectively. Error bars display the standard error of the mean. * $p < .05$.

task; third, overall RTs are faster for the physical task than for the numerical task. These results clearly show that the interaction between numerical value and physical size is not symmetrical when task and instructions are taken into account. That is, "choose larger" produces a larger SiCE than "choose smaller" for numerical but not for physical (i.e., size) comparisons. In order to better understand this pattern of interaction, in the present study we analyzed both RTs and the time course of these responses across congruity conditions for both number and physical size judgments.

Previous studies looking at the interactions between number and physical size have used the average RTs associated with the congruent and incongruent conditions. Here we look at both mean RTs and RT distributions. The advantage of analyzing RT distributions by means of applying a binning procedure is that it allows mapping the time course of the congruity effect. The binning procedure entails dividing the entire RT distribution into a number of equal intervals from fastest to slowest time. It provides a sensitive way to capture possible asymmetries in the pattern of responses associated with physical size and number. This method has been used extensively to map the time course of interference in different cognitive tasks (see Cohen, Bayer, Jaudas, & Gollwitzer, 2008; De Jong, Liang, & Lauber, 1994; Hommel, 1996; Meiran & Kessler, 2008; Oberauer, 2005), and more recently, it has been applied to address asymmetries in the interaction between time and numbers (Arend, Cappelletti, & Henik, 2014). In the context of the SiCE effect, the binning procedure can be useful to address the impact of the irrelevant dimension (either physical size or number) on responses. If number and physical size differ in terms of the level of automaticity with which they are processed (e.g., physical size being processed in a more automatic fashion than number), there may be different time courses associated with physical size and number, such that physical size produces earlier interference on number processing, whereas number produces relatively late interference on physical size processing.

Experiment 1

Participants

Sixty neurologically healthy participants with normal or corrected-to-normal vision (42 females, mean age 23 years, $SD = 1.50$) took part in the present study. All were right-handed psychology students at Ben-Gurion University of the Negev who received course credits to participate and provided written consent to take part in the experiment. The study was approved by the Ben-Gurion University of the Negev Ethics Committee.

Stimuli and Procedure

The experiment was programmed using E-prime software (E-Prime, Psychology Software Tools) running on a Dell OptiPlex 760 vPro computer with an Intel core 2 duo processor. Pairs of Arabic numbers from 1 to 9 were used. In order to create different trial types, we used four pairs of numbers for distance 2 (i.e., 1–3, 2–4, 6–8, 7–9) and four pairs of numbers for distance 5 (i.e., 1–6, 2–7, 3–8, 4–9). We also used two pairs of physical sizes. For one pair, the vertical visual angle was 2.3° and 1.5° for the large and for the small stimulus, respectively; for the other pair, the vertical visual angle was 1.7° and 1.0° for the large and for the small number, respectively. Numbers were presented at the center of the computer screen, 4° apart. Stimuli were presented in white on a black background. It has been argued that for some pairs of numbers the task can be solved without performing a number comparison. This is because participants may notice that for the pairs 1–3, 7–9, 1–6, and 4–9, the numbers 1 and 9 are always the smaller or the larger in the pair. In order to prevent this confound, we performed the data analysis only for the pairs 2–7, 3–8, 2–4, 6–8.

A trial started with a fixation cross for 500 ms. Following the offset of the fixation cross, two numbers appeared simultaneously at the center of the display. Participants were required to indicate the location of the target in each trial by using the *z* and the *m* keys of the computer keyboard for left and right responses, respectively. Participants were encouraged to respond as fast as possible while avoiding mistakes. For the numerical task, one group of participants reported the location of the large number (number-large task), and the other group reported the location of the small number (number-small task). For the physical task, one group of participants reported the location of the large stimulus (physical-large task), and the other group reported the location of the small stimulus (physical-small task). Therefore, there were four groups of participants: number-large, number-small, physical-large, and physical-small.

Design

We used a mixed design. Congruity (congruent vs. incongruent), numerical distance (2 vs. 5), and target location (left vs. right) were within-subjects factors. Task (numerical vs. physical) and polarity of instructions (report large vs. report small) were between-subjects factors. Each participant carried out 12 practice trials during which they received feedback. There were five experimental blocks of 64 trials each, resulting in a total of 320 experimental trials for each task. The experiment took approximately 30 min to be completed. Participants were debriefed at the end of the experiment.

Results

The error rate was generally low (less than 3%), and therefore errors were not analyzed. The analysis of RTs was performed for correct trials only. RTs faster than 150 ms or slower than 1,500 ms were removed from the analysis. The proportion of trials discarded due to this procedure was 2%. Because the numerical distance did not interact with the factors of theoretical relevance, namely task and polarity of instructions, we did not include numerical distance in the analysis.[1]

Mean RTs were subjected to a four-way mixed analysis of variance (ANOVA) with congruity (congruent vs. incongruent) as a within-subjects factor, and task (numerical vs. physical) and polarity of instructions (choose large vs. choose small) as between-subjects factors. Results are shown in Figure 1, panel B. The following main effects reached significance: congruity, $F(1, 56) = 131.64$, $p < .001$, $\eta_p^2 = .70$, as RTs for congruent trials were faster (444 ms) than for incongruent trials (475 ms); task $F(1, 56) = 70.08$, $p < .001$, $\eta_p^2 = .56$, RTs were slower for the numerical (524 ms) than for the physical task (395 ms); and polarity of instructions, $F(1, 56) = 8.18$, $p = .006$, $\eta_p^2 = .13$, showing that RTs were overall faster when the task required choosing the larger (438 ms) as opposed to the smaller (482 ms) digit.

Congruity was affected by task, $F(1, 56) = 29.07$, $p < .001$, $\eta_p^2 = .34$, revealing a larger effect for the numerical (501 ms vs. 547 ms, for congruent and incongruent trials, respectively) than for the physical task (386 ms vs. 403 for congruent and incongruent trials, respectively); and by polarity of instructions, $F(1, 56) = 7.96$, $p < .001$, $\eta_p^2 = .12$. Independent *t* tests showed that only for congruent trials, RTs were faster when participants were choosing the larger target (418 ms) as opposed to when participants were choosing the smaller target (470 ms), $t(58) = 2.40$, $p = .02$.

Of major theoretical relevance is the *three*-way interaction involving congruity, task, and polarity of instructions, $F(1, 56) = 16.19$, $p < .001$, $\eta_p^2 = .22$. This interaction is depicted in Figure 1 (panel B). We examined this interaction by two sets of 2 × 2 mixed ANOVAs with congruity and instructions as independent variables, separately for the number and the physical task. For the number task, congruity was modulated by polarity of instructions, $F(1, 28) = 15.01$, $p < .001$, $\eta_p^2 = .35$. An independent *t* test revealed that this interaction was due to the larger congruity effect (incongruent minus congruent RT) for the number task (64 ms) relative to the physical task (28 ms). For the physical task, the interaction between congruity and polarity of instructions did not reach significance, $F(1, 28) = 1.65$, mean squared errors (*MSEs*) $= 160.9$, $p = .210$, $\eta_p^2 = .06$. That is, the congruity effect for choose the larger condition (13 ms) did not significantly differ from the congruity effect for choose the smaller condition (19 ms).

Time course effects. In order to compare the time course of the congruity effect, we conducted a repeated-measures ANOVA on mean RTs taking congruity (congruent vs. incongruent) and bins (1 to 5) separately for each task and instructions. Results are shown in Figure 2. For the number-large task (Figure 2, upper right panel), only the main effect of congruity was significant, $F(1, 14) = 62.53$, $p = .05$, $\eta_p^2 = .82$, but not the interaction between the two factors, $F(4, 56) = 1.29$, $p = .28$, $\eta_p^2 = .08$. These results illustrate that the irrelevant physical dimension affected RT regardless of bin.

For the number-small condition (Figure 2, upper left panel), there was a significant main effect of congruity, $F(1, 14) = 14.26$, $p = .002$, $\eta_p^2 = .51$, and the interaction between congruity and bins, $F(1, 14) = 14.72$, $p < .001$, $\eta_p^2 = .51$, reached significance. Polynomial contrasts revealed that this interaction was due to a linear decrease of the congruity effect across bins, $F(1, 14) = 14.25$, $p = .002$, $\eta_p^2 = .50$. Bonferroni-corrected tests revealed that congruity was significant in bins 1, 2, and 3 ($p < .01$).

Results for the physical-large condition (Figure 2, lower right panel) revealed both the main effect of congruity, $F(1, 14) = 12.63$, $p < .003$, $\eta_p^2 = .47$, and the interaction between congruity

[1] There was a main effect of numerical distance, $F(1, 56) = 32.35$, $p < .001$, $\eta_p^2 = .37$, showing that RTs for distance 5 were faster than for distance 2 (452 ms and 466 ms, respectively). The three-way interaction involving congruity, numerical distance, and instructions did not reach significance, $F(1, 56) = 1.53$, $p = .22$, $\eta_p^2 = .03$.

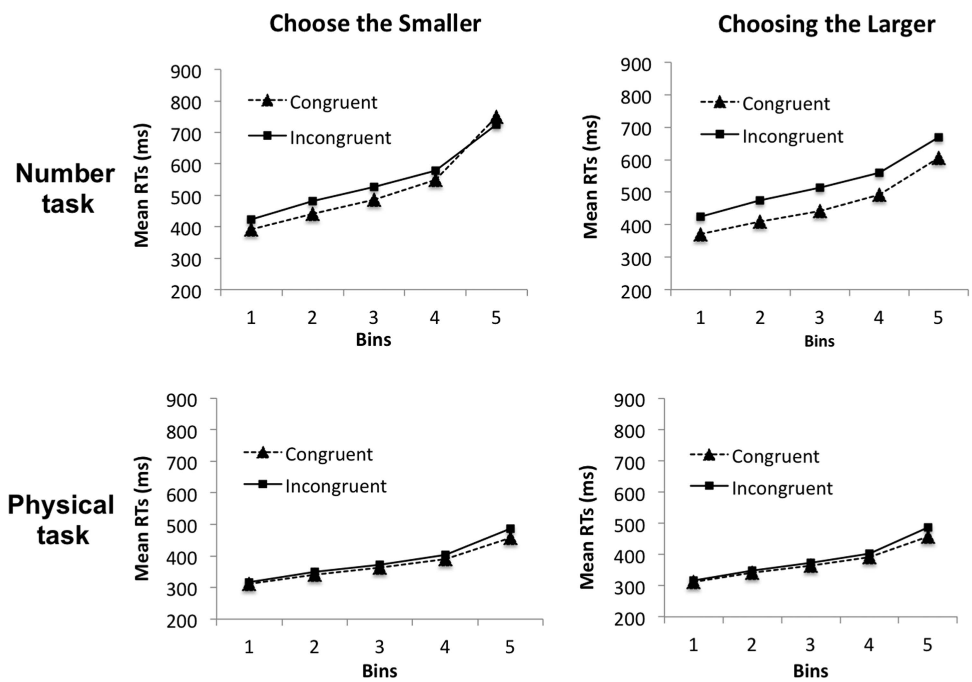

Figure 2. Time course effects for Experiment 1. Mean RTs as a function of bins (1 to 5) for "choose the smaller" and "choose the larger" conditions separately for the number task (first row) and the physical task (second row). Dashed lines represent mean RTs for congruent trials and continuous lines represent mean RTs for incongruent trials.

and bins, $F(4, 56) = 7.67$, $p < .0001$, $\eta_p^2 = .35$. Polynomial contrasts revealed a significant linear decrease in effect across bins, $F(1, 14) = 8.88$, $p = .01$, $\eta_p^2 = .39$. Bonferroni-corrected tests confirmed that the congruity effect reached significance in bin 3, $p < .01$; bin 4, $p < .01$; and bin 5, $p < .01$.

Similarly for the physical-small condition (Figure 2, lower left panel), both the main effect of congruity, $F(1, 14) = 32.63$, $p < .0001$, $\eta_p^2 = .70$, and the interaction between congruity and bins were significant, $F(4, 56) = 4.85$, $p = .002$, $\eta_p^2 = .26$. Polynomial contrasts showed a linear increase in the congruity effect as a function of bins, $F(1, 14) = 7.32$, $p = .02$, $\eta_p^2 = .34$. Bonferroni-corrected tests confirmed a reliable congruity effect in bin 3 ($p < .01$).

Interim Discussion

Our results clearly show that the SiCE in the number task is modulated by the polarity of instructions, whereas in the physical task it is not. These patterns nicely corroborate those reported by Tzelgov et al. (1992). Before we elaborate why these results cannot be explained by the attentional account proposed by Risko and colleagues (2013), we would like to address a possible methodological limitation of our study. The present study uses two numerical distances—2 and 5. Because the numbers 1 and 9 are always the smallest and the largest of the stimulus set, in pairs that include these numbers subjects are able to decide which one is the larger or the smaller without having to perform a number comparison. Accordingly, we removed these numbers from the analysis. However, when we remove pairs with the numbers 1 and 9, the problem persists since the number 2 and the number 8 are the smaller and the larger, respectively, of the remaining pairs. For example, the number 2 is never the larger, and the number 8 is never the smaller in the remaining pairs. Therefore, it is possible that after a few trials, participants were able to build a strategy to respond to the larger and to the smaller digit of the pair without actually having to compare the numbers. In order to overcome this limitation, in Experiment 2 we used sets of digits in which the same number could be either the smaller (e.g., 2–3) or the larger (e.g., 2–1) in various pairs (please see Stimuli and Procedure of Experiment 2 below). In other respects, the method was exactly the same as the one used in Experiment 1.

Experiment 2

Participants

Sixty neurologically healthy participants with normal or corrected-to-normal vision (48 females, mean age 23 years, *SD* = 1.20), who did not take part in Experiment 1, received course credit to take part in the present experiment. Five were left-handed. Participants provided written consent to take part in the experiment. The study was approved by the Ben-Gurion University of the Negev Ethics Committee.

Stimuli and Procedure

In order to create conditions in which the same number could be the larger and the smaller within various pairs of digits, we used distances 1 and 2 only. The following pairs were used for distance 1: 1–2, 2–3, 3–4, 4–5, 5–6, 6–7, 7–8, 8–9; and for distance 2:

1–3, 2–4, 3–5, 4–6, 5–7, 6–8, 7–9. Please note that in pairs of distance 1, the numbers 1 and 9 are always the smallest or largest, respectively, and in pairs of distance 2, the numbers 2 and 8 are always the smallest or largest, respectively. Still, even if we do not include these numbers in the analysis, there are enough pairs that include numbers that can be either smaller or larger in different pairs (e.g., 3 is the larger digit in pair 2–3 and the smaller digit in pair 3–4 with distance 1, and it is the larger digit in pair 1–3 and the smaller digit in pair 3–5 with distance 2).

Design

We used a mixed design. The factors of theoretical relevance were congruity (congruent vs. incongruent) as a within-subjects factor, and task (number vs. physical) and polarity of instructions (report large vs. report small) as between-subjects factors. Each participant carried out 12 practice trials during which they received feedback. There were 4 experimental blocks of 120 trials each, resulting in a total of 480 experimental trials for each task. The experiment took approximately 35 min to be completed. Participants were debriefed at the end of the experiment.

Results

The error rate was low (less than 2%), and therefore errors were not analyzed. The analysis of RTs was performed for correct trials only. RTs faster than 150 ms or slower than 1,500 ms were removed from the analysis, resulting in 3% of the trials being removed due to this procedure.

Mean RTs were subjected to a mixed ANOVA with congruity (congruent vs. incongruent) as a within-subjects factor, and task (numerical vs. physical) and polarity of instructions (choose large vs. choose small) as between-subjects factors. Results are shown in Figure 1, panel C. The following mains effects reached significance: congruity, $F(1, 56) = 120.13$, $p < .001$, $\eta_p^2 = .68$, as RTs for congruent trials were faster (515 ms) than for incongruent trials (546 ms); and task, $F(1, 56) = 52.20$, $p < .001$, $\eta_p^2 = .48$, as RTs for the physical task were faster (449 ms) than for the number task (611 ms). The main effect of polarity of instructions was not significant, $F(1, 56) = 2.05$, $p = .16$, $\eta_p^2 = .04$. Congruity was modulated by task, $F(1, 56) = 17.19$, $p < .001$, $\eta_p^2 = .24$, and by polarity of instructions, $F(1, 56) = 5.73$, $p = .02$, $\eta_p^2 = .09$, but polarity of instructions was not affected by task, $F(1, 56) = 1.67$, $p = .20$, $\eta_p^2 = .03$. Of main relevance for the present report is the significant three-way interaction, $F(1, 56) = 14.40$, $p < .001$, $\eta_p^2 = .21$, reflecting the pattern of results depicted in Figure 1, panel C.

We examined the three-way interaction by two 2 × 2 mixed ANOVAs with congruity and polarity of instructions as independent variables, separately for the number and the physical task. For the number task, congruity was modulated by polarity of instructions, $F(1, 28) = 10.44$, $p = .003$, $\eta_p^2 = .27$. An independent *t* test revealed that this interaction was due to the larger congruity effect (incongruent minus congruent RT) in the "choose the larger" (59 ms), relative to the "choose the smaller" condition (24 ms), $t(28) = 3.56$, $p < .001$. For the physical task, the interaction between congruity × polarity of instructions did not reach significance, $F(1, 28) = 1.98$, $MSEs = 229.90$, $p = .17$, $\eta_p^2 = .07$, since the congruity effect observed under "choose the larger" condition (15 ms) and under "choose the smaller" (23 ms) did not differ significantly. Taken together, these results successfully replicated the findings from Experiment 1.

In order to analyze whether the present findings could still be affected by the so-called end effect, we removed from the analysis the pairs containing the numbers 1 and 9 for distance 1 and the numbers 2 and 8 for distance 2. Mean RTs were entered in the same mixed ANOVA model taking congruity as a within-subjects factor, and task and polarity of instructions as between-subjects factors. Because the results were virtually the same as those reported in the previous analysis, we will concentrate on the decomposition of the three-way interaction. The three-way interaction reached significance, $F(1, 56) = 5.47$, $p = .02$, $\eta_p^2 = .09$. Polarity of instructions modulated the congruity effect in the number task, $F(1, 28) = 6.93$, $p = .01$, $\eta_p^2 = .20$, as the congruity effect was larger under "choose the larger" (49 ms) than under "choose the smaller" (25 ms). However, polarity of instructions did not modulate the congruity effect in physical task, $F(1, 28) = 1.80$, $MSEs = 342.06$, $p = .19$, $\eta_p^2 = .06$, since a similar congruity effect was observed under choose the larger (15 ms) and under choose the smaller (24 ms) conditions. These results are in agreement with those reported in Experiment 1. That is, polarity of instructions modulated the SiCE in the number tasks, but not in the physical tasks. Therefore, our results do not seem to be derived by strategies involving the end effect, but by number comparison processes.

Time course effects. We examined the time course effects by means of a repeated-measures ANOVA on mean RTs, taking congruity (congruent vs. incongruent) and bins (1 to 5) separately for each task and instructions. Results are shown in Figure 3. For the number-large task (Figure 3, upper right panel), only the main effect of congruity was significant, $F(1, 14) = 71.23$, $p < .001$, $\eta_p^2 = .83$, but not the interaction between the two factors, $F(4, 56) = 1.43$, $p = .24$, $\eta_p^2 = .09$. These results illustrate that the irrelevant physical dimension affected RT regardless of bin.

For the number-small condition (Figure 3, upper left panel), there was a significant main effect of congruity, $F(1, 14) = 12.81$, $p = .003$, $\eta_p^2 = .48$, and also for the interaction between the two factors, $F(4, 56) = 5.54$, $p < .001$, $\eta_p^2 = .28$. Polynomial contrasts revealed a significant linear decrease in effect across bins, $F(1, 14) = 7.66$, $p = .02$, $\eta_p^2 = .35$. Bonferroni-corrected tests confirmed that the congruity effect reached significance in bin 1, 2, and 3 (all p values $< .01$).

For the physical-large condition (Figure 3, lower right panel), there was a significant main effect of congruity, $F(1, 14) = 54.12$, $p < .001$, $\eta_p^2 = .79$, and a significant interaction between the two factors, $F(4, 56) = 8.02$, $p < .001$, $\eta_p^2 = .36$. Polynomial contrasts revealed a significant linear increase in effect across bins, $F(1, 14) = 20.00$, $p < .001$, $\eta_p^2 = .58$. Bonferroni-corrected tests confirmed that the congruity effect reached significance in bin 3, 4, and 5 (all p values $< .01$).

For the physical-small condition (Figure 3, lower left panel), the main effect of congruity reached significance, $F(1, 14) = 19.10$, $p < .001$, $\eta_p^2 = .58$, and a significant interaction between the two factors, $F(4, 56) = 9.01$, $p < .001$, $\eta_p^2 = .39$. Polynomial contrasts revealed a significant linear increase in effect across bins, $F(1, 14) = 13.86$, $p = .002$, $\eta_p^2 = .50$. Bonferroni-corrected tests confirmed that the congruity effect reached significance in bins 3, 4, and 5 (all p values $< .01$).

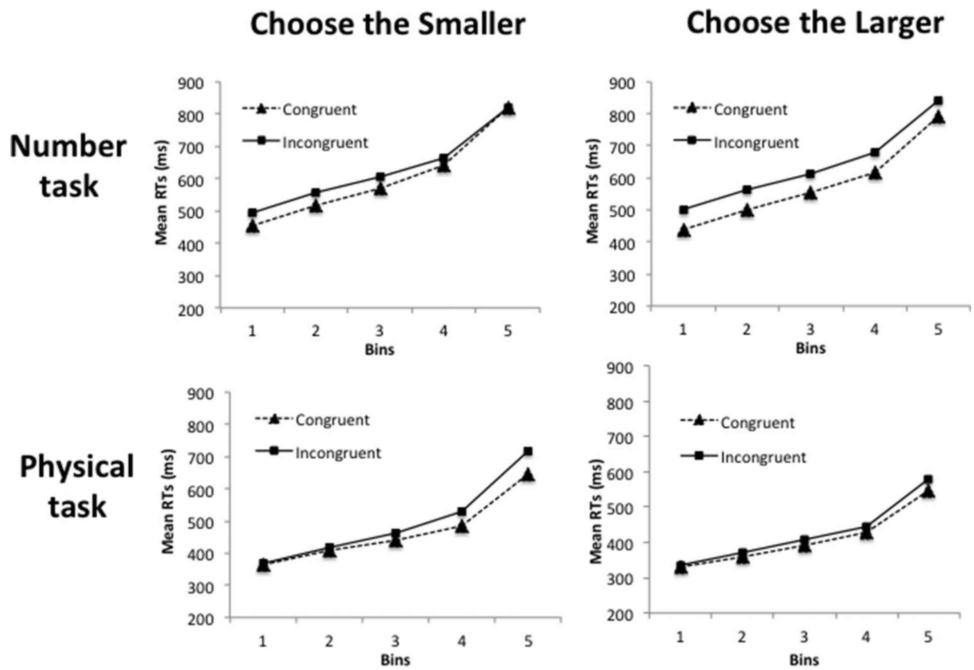

Figure 3. Time course effects for Experiment 2. Mean RTs as a function of bins (1 to 5) for "choose the smaller" and "choose the larger" conditions separately for the number task (first row) and the physical task (second row). Dashed lines represent mean RTs for congruent trials, and continuous lines represent mean RTs for incongruent trials.

In summary, the results reported here clearly replicate the pattern reported in Experiment 1. That is, the time course effects for the number task reveal the early impact of the physical dimension on RTs, whereas the time course for the physical task reveals the late impact of symbolic numerical information on RTs.

Discussion

The present study aimed to examine the effects of task (number vs. physical size) and polarity of instructions (choose large vs. choose small) in the SiCE. Our results can be summarized as follows: (1) the SiCE was larger for the numerical relative to the physical task; (2) polarity of instructions affected only the numerical task, so that the SiCE was larger under *choose the larger* number than under *choose the smaller* number; and (3) analysis of RT distributions showed a different time course for number and physical size tasks. That is, the physical dimension affected number comparison from early bins, whereas number affected physical comparison at later bins. It is important to note that asymmetries in RTs reported here nicely resemble those observed in Tzelgov et al.'s (1992) data (see Figure 1, panel A).

Shared representation or attention capture? Can the effects of task and polarity of instructions be explained by shared representation or attentional accounts for the SiCE? A shared representation account predicts that different dimensions (e.g., number and physical size) should interact symmetrically. Symmetrical interactions are expected following the proposal by Meck and Church (1983) that magnitude representation based on, for example, timing, could be used in subsequent number discriminations. According to this rationale, if numerical value and physical size are processed by a single device, the impact of numerical value on physical size and of physical size on numerical value should be equivalent. Our results showing larger SiCE under conditions of "choose the larger," as well as those reported by Tzelgov and colleagues (1992) are not consistent with the predictions from a shared representation account.

The presence of such asymmetries is consistent with the idea of a partially shared representational system (Arend et al., 2014; Bueti & Walsh, 2010; Cappelletti, Freeman, & Cipolotti, 2009, 2011). According to this view, besides sharing a single representational system, different dimensions (e.g., time, numbers, and space) are implemented by domain-specific processes. For example, when asked to compare the numerosity or the duration of two stimulus sets (i.e., which set has more items or lasted longer?), participants frequently report the longer durations in the presence of larger sets (larger numerosity), but duration has no impact on numerosity judgments (Dormal, Seron, & Pesenti, 2006; Roitman, Brannon, Andrews, & Platt, 2007). These asymmetries have been interpreted to reflect differences in saliency between dimensions (Dormal et al., 2006). The asymmetries in the SiCE as a function of task and polarity of instructions indicate that the process involved in physical and numerical comparisons may rely on different coding processes, as for example, saliency and access to long-term representation. We expand on this idea later in this section.

Our results cannot be explained by a *response decision* account for the SiCE (Santens & Verguts, 2011). According to this account, the SiCE originates at the response decision level and not at the representational level. For example, in congruent trials, both dimensions activate the same response (e.g., if participants are looking for the larger number in the pair 2 4, both dimensions signal "right" response), whereas in incongruent trials, the relevant and the irrelevant dimension activate opposite responses ("left" and "right" responses). The response decision model formulated by Santens and Verguts (2011; see also Verguts, Fias, & Stevens, 2005) predicts that the interaction between any magnitude dimensions originates at the response decision level. That is, the SiCE (or congruity involving any other dimension) should be observed whenever two dimensions share the same responses. In its current form, this account cannot explain the fact that polarity of instructions and task modulated the SiCE, as response decisions (larger vs. smaller) were the same across all tasks.

Risko and colleagues (2013) offered an attentional contribution for the SiCE. In the introduction, we presented a number of methodological limitations in Risko and colleagues' study that opened the possibility that their findings may not be due to attention. Even though Risko and colleagues consider some influence of magnitude processes in the SiCE, their proposal does not describe how attention and magnitude mechanisms operate across different dimensions (task-relevant feature) and across different instructions (choose the smaller vs. choose the larger). Therefore, their proposal cannot account for the pattern of results presented here, specifically, the fact that the physical task was not affected by polarity of instructions (i.e., by attention). In contrast, a saliency-based account, which might be related to Risko and colleagues' notion of attention, might explain the pattern of results reported here. We turn to this now.

Saliency-based and long-term representation processes in the SiCE. The term *saliency* appears in a number of reports discussing the presence of asymmetries in the context of magnitude interactions (Cappelletti et al., 2011; Dormal et al., 2006; Santens & Verguts, 2011). However, a description on how saliency and the access to long-term symbolic representations contribute to the SiCE has not been formulated. Even though partially shared accounts for the SiCE predict asymmetries across different dimensions, the partially shared account is silent with respect to how the comparison of different dimensions are performed and what produces asymmetries. Here we propose that the effects of task and polarity of instructions, observed in the SiCE, reflect the role of saliency-based and long-term representation processes in physical size and number comparison tasks. We follow the definition of saliency offered by Michael and Gálvez-García (2011): "Visual salience is not a physical property of an item, but the relationship between that item and other items in the scene. It results from a comparison of elementary visual features and serves to order inputs for further processing. This ordering, or hierarchy, is thus the aspect likely to be the most relevant for orienting of attention." (p. 87).

Different visual features such as color, size, orientation, and motion are coded in specialized feature maps (Koch & Ullman, 1987; Treisman & Gelade, 1980). These maps are composed of the differences in the levels of activation between various features. As an output, different levels of activation feed into a saliency map representing the location of individual features. Attention, as a saliency-based phenomenon (Theeuwes, 1991), is allocated across the saliency map to features exhibiting greater activity. In a task involving determining which of two competing stimuli is the *physically* larger, the comparative judgments rely on the summed activity of the physical size within the saliency map. Differences in the level of activation within the feature map trigger an attention capture effect to the location of the target. Here we propose that comparisons of physical dimensions rely to a great extent on this saliency-based effortless process. The two experiments reported here and also those reported by Tzelgov and colleagues (1992) agree with this possibility. The physical task is not affected by instructions (i.e., choose larger vs. choose smaller) because the decision with respect to the location of the target is based on the same activation pattern within the saliency map for both target types, larger and smaller. As the visual input consists of only two stimuli (one large and one small stimulus), once the feature map has signaled the location of the large stimulus, the location of the small stimulus can be efficiently inferred. This idea is in accord with the proposed load-insensitivity in feature search involving salient dimensions (Theeuwes, 1991). That is, when search for a target defined by one feature is performed in parallel (preattentively), top-down modulations, derived from either the number of items in the set or from task instructions, do not take place. The time course results for the physical tasks relative to the numerical tasks show that the decisions based on visual saliency occur early in time (e.g., physical size on numbers) in comparison with decisions based on long-term sematic representations (e.g., numbers on physical size). A similar pattern of results has been reported when duration and numerical symbolic information are used (Arend et al., 2014).

In the number comparison tasks, the numerical (semantic) information about the digits must be retrieved from long-term memory in order to be available for a comparative judgment. Under the *choose the larger* number condition, the target is also the larger number in the congruent condition; therefore, the bottom-up activity from the saliency map and the one derived from long-term semantic representation are in agreement. Namely, the physical size of the stimulus accelerates the processing of the slower processed numerical information. That is, the information from the saliency map boosts the processing of sematic numerical information, producing a large congruity effect in the *choose the larger* condition. In the *choose the smaller* condition, the most salient item in congruent trials is not the target, but the physically larger distractor. Therefore, the fast computation of size is not beneficial for accelerating the number comparison. This idea is consistent with the findings showing larger congruity effects for the number task when participants choose the larger as opposed to when they choose the smaller stimulus.

The time course analysis reported is also in agreement with the possibility that physical size constitutes a more salient dimension relative to number, supporting our proposal that physical and numerical comparisons rely on different coding processes. Whereas physical size affected number judgments from early RTs, number affected physical size at later RTs. That is, since the coding of physical size is based on bottom-up activation from a saliency map, its computation occurs rapidly and effortlessly. On the other hand, the processing of numbers, even though highly automatic, relies on the access of long-term semantic representations, which produces later effects in response times. These differences in time course are corroborated by findings showing early ERP (even-related potentials) modulations for the physical relative to the numerical task (Szűcs & Soltész, 2007). The same study reported significant differences between numerical and physical tasks involving the facilitation component (congruent minus neutral trial RT). That is, whereas the facilitation for the numerical task appeared at both perceptual and response levels, facilitation for the physical task appeared at the response decision level. Szűcs and Soltész interpreted these findings as reflecting that in number tasks, the faster irrelevant physical information can affect the early comparison processes and also response selection, whereas the slower processing of irrelevant numerical information can only effect later stages of response processing during size comparison.

Taken together, our behavioral findings are consistent with the idea of a partially shared magnitudes system (Bueti & Walsh, 2010). However, we extend the ideas developed in partially shared accounts to propose that the differences in the SiCE depend on the extent to which the processing of each dimension relies on saliency or on long-term semantic processes. Comparative judgments based on feature saliency may not be strongly integrated with long-term sematic representation, producing symmetrical congruity effects for the two comparisons (i.e., choose larger vs. choose smaller). Even though our proposal has been developed to account for asymmetries in the context of the SiCE, the same account can be applied to understand the processing of other continua that may entail different levels of saliency such as speed of motion, luminance, and color. The fact that magnitude interactions may be sensitive to feature saliency has been previously considered, for example, in the context of number, luminance, and size (Pinel et al., 2004); time and quantity (Dormal et al., 2006); and time and number (Arend et al., 2014; Cappelletti et al., 2011).

Ashkenazi, Rubinsten, and Henik (2009) reported effects of cognitive load on a size congruity task in which participants were asked to report the larger stimulus. Results showed reduced facilitation and increased interference for both physical and numerical tasks. The authors interpreted these findings as reflecting that difficulties in recruiting attention impair different levels of number processing. These results suggest the possibility that attentional factors not related to the properties of the stimuli per se, but to the experimental setting, may also modulate the processing of numbers and physical size.

A possible limitation for the saliency-based account proposed here is the fact that the SiCE can be observed when only one digit is presented[2] (Santens & Verguts, 2011; Schwarz & Ischebeck, 2003; Tzelgov et al., 1992). At this point, it is not clear whether comparison mechanisms operating in two- versus one-digit tasks are the same, and whether asymmetrical patterns arise in one-digit tasks. One could speculate that comparison processes based on internal representation (i.e., the standard digit 5 or the medium size of a number) would not be sensitive to bottom-up signals. The reason for this suggestion is that the differences in saliency arise from differences between visual objects (i.e., saliency is not a property of one item but between one item relative to another). Future studies should address whether different levels of saliency are observed when one of the items is internally represented and not physically presented, and whether these differences would produce asymmetries in the SiCE.

Our account suggesting that nonsymbolic magnitude comparisons may rely on visual saliency is in line with recent theoretical developments in magnitude processing, that is, the idea that neural structures developed to process physical size may have been used to develop an exact number system (Henik, Leibovich, Naparstek, Diesendruck, & Rubinsten, 2011). Recent findings showing that comparative judgments do not always comply with Weber's law (Leibovich, Ashkenazi, Rubinsten, & Henik, 2013) support the proposal presented here. It is possible that subcortical evolutionarily old structures providing visual saliency were the first stations for coding size and noncountable amounts. Saliency maps have been found, for instance, in the pulvinar (Robinson & Petersen, 1992), the parietal cortex (Gottlieb, Kusunoki, & Goldberg, 1998), and some areas of the occipito-temporal pathway (Reynolds & Desimone, 2003). One potential direction for future research is to explore the behavioral and neural correlates of magnitude interaction by using highly salient and symbolic feature dimensions.

[2] We thank one of the anonymous reviewers for addressing this issue.

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