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Transfer of Magnitude and Spatial Mappings to the SNARC Effect for Parity Judgments

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Left–right keypresses to numerals are faster for pairings of small numbers to left response and large numbers to right response than for the opposite pairings. This spatial numerical association of response codes (SNARC) effect has been attributed to numbers being represented on a mental number line. We examined this issue in 3 experiments using a transfer paradigm. Participants practiced a number magnitude-judgment task or spatial stimulus–response compatibility task with parallel or orthogonal stimulus–response dimensions prior to performing a parity-judgment task. The SNARC effect was enhanced following a small–left/large–right magnitude mapping but reversed following a small–right/large–left mapping, indicating that associations between magnitude and response defined for the magnitude-judgment task were maintained for the parity-judgment task. The SNARC effect was unaffected by practice with compatible or incompatible spatial mapping for the parallel spatial task but was larger following up–right/down–left mapping than up–left/down–right mapping for the orthogonal spatial task. These results are inconsistent with the SNARC effect being due to a horizontal number line representation but consistent with a view that correspondence of stimulus and response code polarities contributes to the effect.

Keywords: MARC effect, parity judgments, SNARC effect, SRC effects, transfer of mappings

How numbers are represented is a basic issue in cognitive psychology that is studied in numerical classification tasks (Verguts, Fias, & Stevens, 2005). Performance in such tasks is often faster and more accurate when a left response is made to small numbers and a right response to large numbers than with the opposite stimulus–response (S-R) relations. This result, called the spatial numerical association of response codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993), occurs whether number magnitude is relevant (magnitude-judgment task) or irrelevant (parity- and orientation-judgment tasks; Fias, Lauwereyns, & Lammertyn, 2001).

Mechanisms Underlying the SNARC Effect

Since Dehaene et al. (1993) first reported the SNARC effect, many studies have tried to identify the underlying mechanisms; most results suggest that the effect is due to a trait of number representation. According to Fias, Brysbaert, Geypens, and d'Ydewalle (1996), number representations contain magnitude information. Their Experiment 2 showed a SNARC effect when participants judged whether a specific sound (e.g., /e/) was included in the name of an Arabic digit, but Fias's (2001) Experiment 2 did not show the effect when participants made similar judgments about number words. According to Fias (2001), for digits, number magnitude representations must be accessed to activate their pronunciation; for number words, though, the orthography–phonology conversions do not require accessing number magnitude representations (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001).

A widely accepted metaphor applied to the SNARC effect is that number magnitude is represented spatially on a left-to-right ordered number line (e.g., Gevers, Reynvoet, & Fias, 2003). Because small numbers are located on the left side of the line and large numbers on the right side, small numbers correspond spatially to the left response and large numbers to the right response. The number-line account implies that the SNARC effect is due to spatial correspondence between implicit number location and explicit response location.

Relation Between SNARC and Spatial Compatibility Effects

If the SNARC effect is due to correspondence between left–right location of the target number on a mental number line and left–right response location, then the SNARC effect is closely related to the spatial stimulus–response compatibility (SRC) effect. In two-choice spatial tasks, performance is better when stimulus location corresponds to the response location than when it does not (see Proctor & Vu, 2006). Similarly, when participants respond to an attribute such as color of a stimulus presented in a left or right

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location, performance is still faster and more accurate when the stimulus and response locations correspond, a phenomenon called the *Simon effect* (Simon, 1990).

Dual-route models have been proposed to explain SRC and Simon effects (e.g., Barber & O'Leary, 1997; Kornblum, Hasbroucq, & Osman, 1990), attributing them to response activation produced via automatic and intentional routes. A stimulus produces activation of the corresponding response through the automatic route, which relies on long-term memory (LTM) associations between stimulus and response locations. The stimulus produces activation of the response assigned for the task through the intentional route, which relies on short-term memory (STM) associations defined for the task. Responses are slower and less accurate when the responses activated by the routes conflict than when they do not.

According to the number-line account of the SNARC effect in the parity-judgment task, the location code of the irrelevant magnitude information activates its spatially corresponding response through the automatic route, and the relevant parity information activates its assigned response through the intentional route. These activations produce correspondence or conflict on a trial, as in a Simon task. That the SNARC effect may be explained by a dual-route model is supported by Gevers, Ratinckx, De Baene, and Fias (2006), who found that the lateralized readiness potential (more brain activation over the motor cortex of one cerebral hemisphere than the other) showed an initial difference to the side of the incorrect response for incompatible SNARC trials before switching to the side of the correct response, as occurs in spatial Simon tasks (e.g., De Jong, Liang, & Lauber, 1994). The difference between the Simon and SNARC effects is that the spatial stimulus information is explicit for the former but implicit for the latter.

Several studies have tried to reveal the processing architecture underlying Simon and SNARC effects. Using additive factors logic (Sternberg, 1969), Mapelli, Rusconi, and Umiltà (2003) argued that the Simon and SNARC effects are caused by distinct processing mechanisms. They presented a target number to the left or right of a fixation point; participants were to respond to the number parity and ignore its location. Both Simon and SNARC effects occurred, and these effects did not interact. Also, the Simon effect decreased as reaction time (RT) increased, but the SNARC effect did not. On the basis of the lack of interaction and the different temporal distribution functions, Mapelli et al. (2003) concluded that the SNARC effect is not an instance of the Simon effect and that the SNARC and Simon effects arise from distinct processing mechanisms.

However, Gevers, Caessens, and Fias (2005, Experiment 1) found different results in a similar experiment that differed mainly by manipulating the mapping for the parity-judgment task within rather than between subjects. Gevers et al.'s results showed a significant Simon effect for fast responses on SNARC compatible trials that reversed to favor noncorresponding responses for slower responses. This reversed Simon effect for slower responses was not found on the SNARC incompatible trials. Gevers et al. interpreted their results as indicating that SNARC compatibility has an impact on the ability to suppress the irrelevant spatial location information, suggesting a common processing architecture for the Simon and SNARC effects.

Dynamic Aspect of the Response Dimension and Stimulus Representation

The SNARC effect is also obtained with vertically or diagonally arrayed response sets. Ito and Hatta (2004) found a SNARC effect when participants judged whether each number presented on the center of the screen was even or odd by pressing a top or bottom key: Responses were faster and more accurate when the mapping was small numbers to bottom key and large numbers to top key than when it was opposite. This SNARC effect with the vertically arrayed response set was obtained both when the top key was pressed with the right hand and the bottom key with the left hand, and vice versa. Ito and Hatta's results imply that the SNARC effect is not restricted to a horizontally arrayed number representation.

In Experiment 2 of Gevers, Lammertyn, Notebaert, Verguts, and Fias (2006), participants made parity-judgment responses by pressing the *1* or *9* key, located along the right diagonal of the numerical keypad on a computer keyboard, or the *3* or *7* key, located along the left diagonal. With the right diagonal response set, a regular SNARC effect was obtained: The pairings of large numbers and up–right key (the *9* key) and small numbers and down–left key (the *1* key) yielded faster responses than the opposite pairings. However, with the left diagonal response set, no SNARC effect was found. Gevers et al. attributed this interaction to additive effects of horizontal and vertical spatial codes. With the right diagonal set, both horizontal and vertical spatial codes associated with number magnitude activate the same response. With the left diagonal set, horizontal and vertical spatial codes associated with number magnitude activate different responses (e.g., left is associated with small numbers, but up with large numbers), resulting in no SNARC effect.

Finally, Bächtold, Baumüller, and Brugger (1998) showed that coding of number magnitude is not restricted to a left–right order. They found a reversed SNARC effect when participants were told to generate an image of a clock face and classify whether a presented Arabic digit was greater than six or not. This reversal seems to be due to the small numbers being represented on the right of the clock face and the large numbers on the left. On the basis of the results showing different patterns of the SNARC effect obtained with different response dimensions and in different representational contexts, Ito and Hatta (2004) proposed that number magnitude representation does not necessarily have a left-to-right ordered spatial structure.

Correspondence of Code Polarities

Proctor and Cho (2006) developed an alternative account of the SNARC effect based on code polarity: The stimuli and responses in many binary classification tasks are coded categorically, with one member as positive polarity and the other as negative polarity. For spatial locations, these are categorical spatial codes (Kosslyn, 1994), which are propositional representations of the relations among the locations. According to the polarity correspondence principle, responses are faster when stimulus and response polarities correspond than when they do not.

For left–right responses to stimuli in up–down locations, the up–right/down–left mapping often yields a shorter RT than the opposite mapping (e.g., Cho & Proctor, 2003). The polarity correspondence principle attributes this advantage to correspondence of up and right as positive polarity codes and down and left as negative polarity codes for the former mapping but not the latter (Proctor & Cho, 2006). The up–right/down–left advantage is a graded function of response position: The advantage increases as the position at which responses are made is moved into the right hemispace, and it decreases and reverses to favor the up–left/down–right mapping as the response position is moved into the left hemispace (Cho & Proctor, 2002; Michaels, 1989; Michaels & Schilder, 1991). Cho and Proctor (2002) provided evidence that the influence of response eccentricity is a consequence of the overall code polarity being determined by the combined contributions of response codes formed relative to multiple reference frames.

Polarity correspondence also affects performance with orthogonal S-R arrays when stimulus color is the relevant stimulus dimension and the up–down stimulus location is irrelevant (an orthogonal Simon task; Cho, Proctor, & Yamaguchi, 2008; Nishimura & Yokosawa, 2006). As for the basic orthogonal SRC effect, this orthogonal Simon effect is also a graded function of response eccentricity. Though polarity correspondence logically could also be a factor for the more typical two-choice SRC and Simon effects, in which stimuli and responses vary in left and right positions, in that case correspondence of the spatial codes seems to predominate, as in Heister, Schroeder-Heister, and Ehrenstein's (1990) hierarchical model of compatibility effects.

According to the polarity correspondence account of the SNARC effect, the numeric stimuli are coded categorically as large (positive polarity) or small (negative polarity). Gevers, Verguts, Reynvoet, Caessens, and Fias (2006) made a similar assumption of categorical coding in their computational model of the SNARC effect, which attributes the effect to coding of the digits as large or small, allowing for graded strength of the categorical code. Given that right and top are also coded as positive polarity and left and bottom as negative polarity, it follows that performance will be better when large is paired with the right or top response and small with the left or bottom response than with the opposite pairings. For Gevers, Lammertyn, et al.'s (2006) Experiment 2, in which the response set varied along diagonals, polarities of the response alternatives would be coded along both vertical and horizontal dimensions (see, e.g., Rubichi, Vu, Nicoletti, & Proctor, 2006). A SNARC effect is predicted when the responses are along the right diagonal because the polarities of the response codes for the two dimensions are in agreement (e.g., for right-top response, the right code is positive and the top code is positive). However, for the left diagonal, no SNARC effect is predicted because the polarities of response codes for the two dimensions are opposite (e.g., for right-bottom response, the right code is positive and the bottom code is negative).

Mixing and Transfer Paradigms

Two paradigms have shown that the mapping for a task in which spatial location is relevant influences performance of a Simon task for which location is irrelevant. In one paradigm, location-relevant trials are mixed with location-irrelevant trials for which stimulus color is relevant. The Simon effect for the latter trials reverses to favor noncorresponding locations when the mapping for location-relevant trials is incompatible (Marble & Proctor, 2000). This result suggests that on location-irrelevant trials, the stimulus activates the noncorresponding response through the short-term associations defined for the location-relevant task.

Notebaert, Gevers, Verguts, and Fias (2006) examined the SNARC effect in the mixed tasks paradigm. In Experiment 1, magnitude-irrelevant trials (for which digit orientation was relevant) were mixed with magnitude-relevant trials for which the digit was to be classified as less or greater than five. When the magnitude-relevant mapping was incompatible, associating small numbers with right response and large numbers with left response, the SNARC effect for the magnitude-irrelevant task reversed. In Experiment 2, the digit orientation trials were mixed with left–right spatial SRC trials. The former trials showed a regular SNARC effect when the spatial mapping was compatible, but a reversed SNARC effect when it was incompatible. An opposite influence of magnitude-relevant mapping on the spatial Simon effect was observed in Experiment 3. The interaction of spatial mapping with the SNARC effect and magnitude mapping with the Simon effect suggests a common processing architecture for the two effects.

The second paradigm is one in which a location-relevant task with one S-R mapping is practiced prior to transfer to a Simon task for which stimulus location is irrelevant (e.g., Proctor & Lu, 1999). Tagliabue, Zorzi, Umiltà, and Bassignani (2000) had participants practice the spatial SRC task for 72 trials and perform the Simon task 5 min later. A typical Simon effect was evident after practice with the compatible mapping, but the effect was absent after practice with the incompatible mapping. To explain these results, Tagliabue et al. distinguished the STM associations created by Simon-task instruction from those created by performance of the SRC practice task. The former are STM links between a relevant stimulus property (e.g., color) and response for the Simon task, whereas the latter are spatial compatibility STM (SC-STM) links between stimulus and response locations. Tagliabue et al. provided evidence that the SC-STM links are maintained during the transfer Simon task, causing the task-irrelevant stimulus location to activate responses through both LTM and SC-STM links. When the practiced mapping is incompatible, the LTM and SC-STM associations activate different responses, resulting in elimination of the Simon effect.

If the practice and transfer tasks do not share a common representation, then the SC-STM links created in practice will not influence performance of the transfer task. For example, Proctor, Yamaguchi, Zhang, and Vu (2009) found that 72 practice trials with an incompatible mapping of left–right locations or arrow directions produced transfer to a Simon task when the irrelevant location information was conveyed by either mode. However, no transfer was evident when the location information for one of the tasks was conveyed by words, suggesting that locations and arrows share a common spatial representation that words do not. Transfer may also occur if a rule-based procedure is learned in practice (Vu, 2007), an issue we discuss later.

Present Study

To date, no study has examined the SNARC effect in the transfer paradigm. Although this paradigm is similar in some ways to the mixed tasks paradigm used by Notebaert et al. (2006), the two are logically distinct. In the mixing paradigm, the dimension-irrelevant trials (location or digit magnitude) are mixed with trials for which that dimension, with a particular mapping to responses, is relevant. As in task-switching studies (Altmann & Gray, 2008), participants must maintain two task sets and select the one appropriate for a given trial. In contrast, in the transfer paradigm the dimension is irrelevant for all trials in the transfer session. Participants need only to maintain a single task set, and no selection between sets is required. Because performance shows overall mixing costs due to the need to maintain multiple task sets and specific switch costs when the current task is different from that on the prior trial (Altmann & Gray, 2008), the mixing paradigm inevitably involves processes that the transfer paradigm does not.

In agreement with the logical difference between the mixing and transfer paradigms, results obtained with the two are not identical. As one example, a mixed incompatible spatial mapping produces complete reversal of the Simon effect equal to the absolute size of the positive Simon effect obtained with a mixed compatible mapping (Marble & Proctor, 2000), implying that the Simon effect in mixed tasks is determined solely by the SC-STM links. But reversal of the Simon effect is not complete after 72 trials of practice with an incompatible mapping in the transfer paradigm, and the size of reversal increases as the number of practice trials increases (e.g., Proctor, Yamaguchi, & Vu, 2007), suggesting combined contributions of both SC-STM and LTM links. As a second example, in the mixed tasks paradigm the influence of an incompatible mapping on the Simon effect is reduced when the location information is conveyed by arrows for one task and physical locations for the other (Proctor, Marble, & Vu, 2000). But in the transfer paradigm, there is no reduction in transfer when the location modes for the practice and transfer tasks differ (Proctor et al., 2009). This difference suggests that the influence of the mode distinction is on selection between task sets, which is not required in the transfer paradigm.

In the present study, therefore, we examined the influence of the STM links created with different practice tasks on the SNARC effect obtained in a transfer parity-judgment task. Experiment 1 complemented Notebaert et al.'s (2006) Experiment 1, which used the mixed tasks paradigm. The intent was to determine whether, after 72 practice trials with a magnitude-judgment task, the mapping for that task transfers to a parity-judgment task for which magnitude is irrelevant. Experiment 1 sought to establish that associations between large–small numbers and left–right responses (magnitude compatibility [MC] STM links) continue to affect performance when made task irrelevant, as those between stimulus and response locations do.

Experiment 2A was similar to Experiment 1, except that participants practiced an SRC task for which left–right stimulus locations were mapped compatibly or incompatibly to left–right responses. Transfer of the practice mapping to the parity-judgment task through SC-STM links is expected if the SNARC effect is due to left–right coding of magnitude on a number line. Notebaert et al. (2006, Experiment 2) showed that a concurrent location mapping influences the SNARC effect, but for the reasons noted, this does not necessarily mean that a prior location mapping will transfer to the parity-judgment task. In Experiment 2B, practice was extended to 600 trials to provide a stronger test of the transfer predicted by the number line account.

Experiment 3 was like Experiment 2A, except that practice was with an orthogonal SRC task for which up–down stimulus locations were mapped to left–right responses. Modulation of the SNARC effect by the orthogonal SRC mapping would suggest a close relation of that effect to orthogonal SRC, for which the most widely accepted explanation is that of correspondence between stimulus and response code polarities.

Experiment 1

Experiment 1 was designed to determine whether a practiced magnitude mapping would have an influence on performance of the transfer parity-judgment task like that found by Notebaert et al. (2006) when trials for the two tasks were mixed. Participants performed a magnitude-judgment task with one of two mappings for 72 trials and then, after a brief interval, a parity-judgment task. Magnitude information typically produces a Simon-type effect for parity judgments, suggesting that the practiced magnitude-response mapping should affect performance in the transfer session as a mapping of spatial information does for the Simon task. The SNARC effect in the parity-judgment task should be larger after practice with a SNARC compatible mapping (large–right/small–left) than with an incompatible mapping (large–left/small–right), with the SNARC effect possibly reversing in the latter case to favor the practiced relation.

Method

Participants. Twenty-eight undergraduate students (10 male; 18 female) who were enrolled in Introductory Psychology at Korea University participated to fulfill a course requirement. All were right-handed and had normal or corrected-to-normal vision. They were randomly assigned to two practice groups: One performed the practice task with a SNARC compatible mapping (small–left/large–right) and the other with a SNARC incompatible mapping (small–right/large–left).

Apparatus and stimuli. The experiment was programmed with E-prime (Version 1.0; Schneider, Eschman, & Zuccolotto, 2002). Stimuli were presented on the display screen of a microcomputer at a viewing distance of 60 cm. Responses were made by pressing the leftmost or rightmost key among five on a Micro Experimental Laboratory 2.0 response box (Psychological Software Tools, Pittsburgh, PA) with the left or right index finger. The imperative stimuli were Arabic numerals from *2* to *9* (Verdana 28-point font in Microsoft PowerPoint) presented at the screen center. A plus sign was used as a fixation point.

Procedure. The experiment took place in a dimly lit soundproof room. Participants aligned their body midline with the center of the screen and put their index fingers on the response keys. The experiment consisted of two separate sessions, practice and transfer.

In the practice session, participants performed the magnitude-judgment task with compatible or incompatible mapping. The compatible group was instructed to respond to the numbers *2* to *5* by pressing the left key and *6* to *9* by pressing the right key. The incompatible group was instructed with the opposite mapping. Each trial started with the fixation point, which was displayed for 1 s and then replaced with an Arabic numeral, which was presented until a response was made. Participants were instructed to respond as quickly and accurately as possible to the magnitude of the numeral by pressing the left or right key. A 500-Hz tone was presented for 500 ms as feedback through an exterior speaker when an incorrect response was made. After an intertrial interval of 1,000 ms, the fixation point for the next trial was presented. Each participant performed 16 warm-up trials and 72 main trials (nine trials for each number) for the practice session. After finishing the practice session, participants took a 5-min break.

In the transfer session, a parity-judgment task was performed. The experimental procedure was identical to that of the practice session except for the task rule. Half of the participants in each group were told to respond with a mapping of odd numbers to the left key and even numbers to the right key, and half were told the opposite. They performed 16 warm-up and 144 test trials for the transfer session. The experiment lasted approximately 20 min.

Results

For practice and transfer tasks, trials with RT $<$ 200 ms or $>$ 1,250 ms were excluded ($<$1% of trials for both tasks in all experiments, except for the transfer task of Experiment 2B).

Practice magnitude-judgment task. An analysis of variance (ANOVA) with mapping as the factor showed a SNARC effect: RT was shorter for the small–left/large–right mapping (427 ms) than for the small–right/large–left mapping (510 ms), $F(1, 26) = 6.04$, $p = .021$, $MSE = 8{,}015$. A similar ANOVA of percentage of error (PE) data showed no mapping effect ($F < 1$).

The SNARC effect for each number stimulus was expressed as RT when mapped to the right response minus RT when mapped to the left response (dRT; see Figure 1, top panel). These values were entered into a regression analysis with magnitude as predictor per subject. The SNARC effect was captured by the equation $\text{dRT} = -31.675x + 168.27$ ($R^2 = 0.7636$), for which the slope was significantly different from 0, $t(7) = -4.40$, $p < .01$.

Transfer parity-judgment task. ANOVA s were conducted on RT and PE, with practice mapping (small–left/large–right; small–right/large–left) and transfer mapping (odd–left/even–right; odd–right/even–left) as between-subject variables, and SNARC compatibility (small–left/large–right; small–right/large–left) as a within-subject variable. The means are shown in Table 1.

For RT, SNARC compatibility showed no main effect, $F(1, 24) = 2.25$, $p = .147$, but SNARC compatibility interacted with practice mapping (see Table 1), $F(1, 24) = 26.66$, $p < .0001$, $MSE = 608$. Participants who practiced the magnitude-judgment task with small–left/large–right mapping showed a 44-ms SNARC effect, $F(1, 24) = 22.20$, $p < .0001$, $MSE = 608$. In contrast, participants who practiced with small–right/large–left mapping showed a significant –24-ms SNARC effect, $F(1, 24) = 6.71$, $p = .016$, $MSE = 608$.

Transfer mapping showed no main effect or interaction with practice mapping (Fs < 1.0). However, the two-way interaction of SNARC compatibility and transfer mapping was significant, $F(1, 24) = 4.35$, $p = .048$, $MSE = 608$. Simple main-effect analyses for SNARC compatibility showed a nonsignificant –4-ms SNARC effect with the odd–left/even–right parity mapping ($F < 1.0$), but a 24-ms SNARC effect with the odd–right/even–left mapping, $F(1, 24) = 6.42$, $p = .018$, $MSE = 608$. No other effects in the primary RT ANOVA were significant.

Overall PE was 2.31%. Practice mapping interacted with SNARC compatibility (see Table 1), $F(1, 24) = 8.17$, $p = .009$, $MSE = 8.76$. A significant 2.97% SNARC effect was evident when participants practiced the magnitude task with the small–left/large–right mapping, $F(1, 24) = 7.07$, $p = .014$, $MSE = 8.76$, but a nonsignificant SNARC effect of –1.55% when they practiced with the small–right/large–left mapping, $F(1, 24) = 1.91$, $p = .179$, $MSE = 8.76$.

Like the RT data, transfer mapping and SNARC compatibility interacted for PE, $F(1, 24) = 4.35$, $p = .048$, $MSE = 8.76$. Participants who performed with the odd–left/even–right parity mapping showed a nonsignificant SNARC effect of –0.93%, $F < 1.0$, whereas those who performed with the odd–right/even–left mapping showed a SNARC effect of 2.36%, $F(1, 24) = 4.46$, $p = .045$, $MSE = 8.76$. The interaction of Practice Mapping × Transfer Mapping was significant, $F(1, 24) = 4.26$, $p = .050$, $MSE = 11.18$: Participants who used the odd–right/even–left mapping showed a 2.38% SNARC effect; those who used the odd–left/even–right mapping showed a 0.94% SNARC effect, $F(1, 24) < 1.0$. No other effect was significant.

Regression analyses were performed on dRT, as for the magnitude-judgment task. The SNARC effect was evident after practice with the compatible magnitude mapping ($\text{dRT} = -23.57x + 120.67$; $R^2 = 0.9177$) and reversed after practice with the incompatible mapping ($\text{dRT} = 10.059x - 59.386$; $R^2 = 0.8938$; see Figure 1, middle panel). These slopes were different from 0, ts$(7) = -8.18$, and 7.10, ps $< .05$. The larger R^2 for the parity-judgment task than for the magnitude-judgment task is due to the fact that the parity judgments showed relatively continuous functions for which the effect became larger as the number became more extreme, whereas the magnitude judgments showed little difference in SNARC effect size within the small and large categories. These patterns replicate those reported by Gevers, Verguts, et al. (2006).

Control parity-judgment task. To evaluate whether each practice mapping influenced the SNARC effect in the transfer task, we tested 20 new participants (12 men and 8 women) from the same population; they performed the transfer parity-judgment task without prior practice. This control group showed a 22-ms SNARC effect for RT, $F(1, 18) = 22.50$, $p = .0002$, $MSE = 216$, with PE showing a nonsignificant SNARC effect of 1.2%, $F(1, 18) = 3.65$, $p = .07$, $MSE = 3.91$. The RT SNARC effect differed from the 44-ms effect obtained after practice with small–left/large–right mapping, $F(1, 30) = 6.77$, $p = .0142$, $MSE = 290$, and the –24-ms effect obtained after practice with small–right/large–left mapping, $F(1, 30) = 19.31$, $p < .0001$, $MSE = 455$.

It is useful to compare the parity-judgment data for individual numbers after practice with the compatible magnitude mapping to that of the control group with no prior practice (Figure 1, bottom panel). For the control group, the dRT scores were 23 ms more negative for even numbers than odd numbers. This pattern was reversed for the group that received compatible magnitude-judgment practice (Figure 1, middle panel): Even numbers showed more positive difference scores, favoring the left response, than odd numbers. This reversed pattern is due to the following: With compatible magnitude mapping (*2–5* to left and *6–9* to right), the STM links established for *2*, *4*, *7*, and *9* are in opposition to the response assignments for the odd–left/even–right mapping and consistent with them for the odd–right/even–left mapping. The group that practiced with incompatible magnitude mapping (*6*, *7*, *8*, *9* left and *2*, *3*, *4*, *5* right) showed a smoother dRT function for the parity-judgment task, suggesting that the learning in the prac-

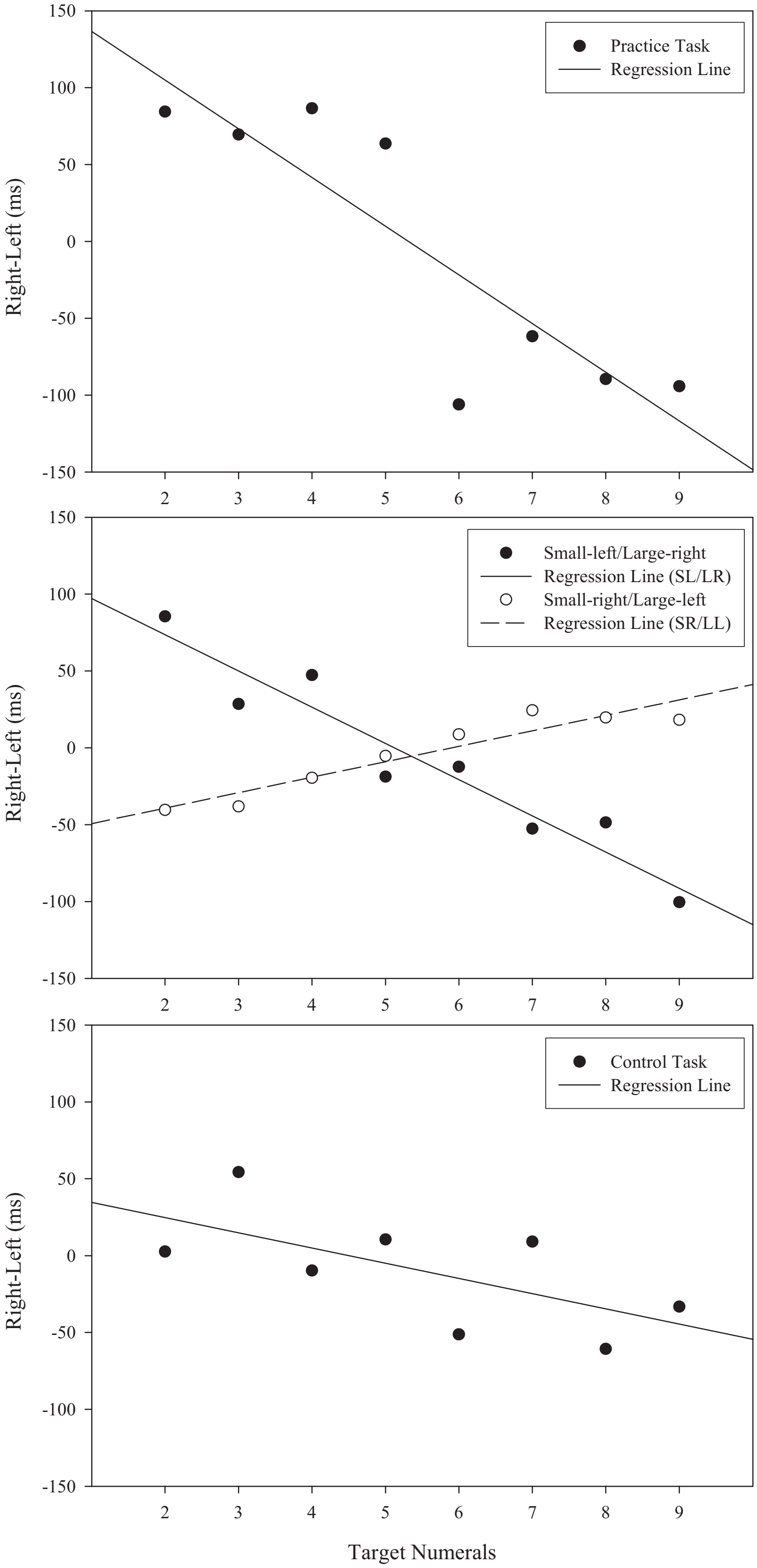

Figure 1. Experiment 1: Difference in reaction time for each number (right response minus left response) with best fitting regression line for the magnitude-judgment practice task (top panel), parity-judgment transfer tasks (middle panel), and the control parity-judgment task (bottom panel).

Table 1

Mean Reaction Time (RT) in ms and Percentage of Error (PE) in Experiments 1, 2A, 2B, and 3 as a Function of Compatibility of Practice Rule, MARC Compatibility, and SNARC Compatibility

			SNARC compatibility					
			Sl/Lr		Sr/Ll		SNARC effect	
Experiment	MARC compatibility	Practice rule	RT	PE	RT	PE	RT	PE
Control	Odd–left/even–right	No practice	476	1.80	490	2.23	14	0.43
	Odd–right/even–left		491	1.39	521	3.35	30	1.96
Experiment 1	Odd–left/even–right	Sl/Lr	498	0.39	527	1.58	29	1.19
		Sr/Ll	533	4.84	495	1.78	−38	−3.06
	Odd–right/even–left	Sl/Lr	456	0.79	514	5.55	58	4.76
		Sr/Ll	523	1.82	512	1.79	−11	−0.03
Experiment 2A	Odd–left/even–right	Compatible	504	1.94	505	2.11	1	0.17
		Incompatible	475	2.22	487	3.61	12	1.39
	Odd–right/even–left	Compatible	456	0.69	483	4.47	27	3.78
		Incompatible	449	1.25	486	2.50	37	1.25
Experiment 2B								
New number set	Odd–left/even–right	Compatible	460	2.28	486	5.79	26	3.51
		Incompatible	449	1.75	462	4.76	13	3.01
	Odd–right/even–left	Compatible	496	1.52	510	4.55	14	3.03
		Incompatible	500	1.25	530	4.82	30	3.57
Original number set	Odd–left/even–right	Compatible	433	3.77	430	4.01	−3	0.24
		Incompatible	527	2.28	551	6.78	24	4.50
	Odd–right/even–left	Compatible	454	1.25	486	6.78	32	5.53
		Incompatible	457	1.27	489	4.53	32	3.26
Experiment 3	Odd–left/even–right	Ur/Dl	491	1.02	514	4.15	23	3.13
		Ul/Dr	492	2.16	499	4.32	7	2.16
	Odd–right/even–left	Ur/Dl	489	1.72	525	4.29	36	2.57
		Ul/Dr	473	1.58	501	6.03	28	4.45

Note. MARC = markedness association of response codes; SNARC = spatial numerical association of response codes; S = small number; L = large number; r = right; l = left; U = up; D = down.

tice session differed in some way from that for the group with compatible magnitude mapping.

Discussion

Performance of the parity judgment-task was influenced by the mapping used for the prior magnitude-judgment practice task. The SNARC effect was 44 ms for participants who practiced with small–left/large–right mapping, but it reversed to –24 ms (a small–right/large–left advantage) for those who practiced with small–right/large–left mapping. Both of these effects differed from the 22-ms effect of the control condition. Experiment 1 confirmed that practice with a mapping of magnitude to responses influences the SNARC effect in the subsequent parity-judgment task by producing activation of the response consistent with the practiced mapping.

This result implies that the short-term S-R associations between number magnitude and response created during the magnitude-judgment task remained active throughout the parity-judgment task. Specifically, when participants performed the magnitude-judgment task, small–left/large–right or small–right/large–left MC-STM links were formed according to the practiced mapping. After practice with the small–left/large–right mapping, the MC-STM links and the LTM links in the transfer session activated the same response (e.g., large numbers activated the right response through both long-term and MC-STM links), resulting in a regular SNARC effect. But, when participants practiced with the small–right/large–left mapping, the MC-STM and LTM links activated different responses (e.g., a large number activated the left response through the MC-STM links and the right response through LTM links), resulting in a reversed SNARC effect.

It is interesting that 72 trials of the magnitude-judgment practice were sufficient to reverse the SNARC effect. The Simon effect for stimulus locations tends only to disappear after incompatible SRC practice for 72 trials and not reverse (Proctor et al., 2009; Tagliabue et al., 2000). The reversal implies that the long-term associations between the implicit number magnitude and the response are not as strong as the short-term S-R associations between them. This conclusion is consistent with the result of Tagliabue et al.'s (2000) Experiment 1, in which young children (ages 5 to 8), who were considered to have weak LTM links, showed a reversed Simon effect when they practiced the SRC task with incompatible mapping for 72 trials.

As in Gevers, Verguts, et al. (2006), the dRT functions showed the SNARC effect to be categorical for the magnitude-judgment task but continuous for the parity judgment task. This raises a question of whether the continuous functions of the parity-judgment task are consistent with a categorical account, such as one in terms of polarity correspondence. It is important to note that Gevers, Verguts, et al. generated these result patterns as predictions from their model in which numbers are categorized as small or large. Santens and Gevers (2008) pointed out the similarity of that account to the polarity correspondence account:

> Both accounts (Gevers, Verguts, et al., 2006; Proctor & Cho, 2006) argue in favor of an extra step in which numerical information is categorized before the activation of a response side. In both "intermediate coding" accounts, numbers are first coded as either small (−) or large (+) and this representation of magnitude is then directly or indirectly associated with spatially defined responses. (p. 265)

The continuous function is produced by Gevers, Verguts, et al.'s (2006) model because activation of a particular category code is greater the farther the number is from the midpoint. The relatively flat functions within categories for the magnitude-judgment task are due to the fact that RTs in that task are longer for numbers nearer the boundary, and the SNARC effect increases as RT lengthens. The difference in functions could come about in other ways, but the main point for our purpose is that continuous as well as discrete functions can arise from categorical coding.

In the transfer session of Experiment 1, participants who performed with the odd–right/even–left parity mapping showed a significant SNARC effect, but those who used the odd–left/even–right mapping showed a nonsignificant, slightly negative SNARC effect. The difference in magnitudes of the SNARC effect when the parity mapping was odd–right/even–left vs. odd–left/even–right was similarly evident for the no-practice control group (with the SNARC effects being 30 ms and 14 ms, respectively), not interacting with a control versus experimental groups comparison ($F < 1.0$). The lack of influence of practice mapping on the SNARC Compatibility × Transfer Parity mapping interaction in Experiment 1 and the similarity of the interaction pattern in that experiment to the pattern obtained for the no-practice control condition indicates that practice with the magnitude-judgment task is not responsible for the interaction.

Experiment 2

Experiment 2 was designed to determine whether practice of a spatial SRC task influences the SNARC effect in the parity-judgment task. The Simon effect, which is thought to have a common mechanism with the SRC effect, is affected by the mapping used by participants in a prior SRC task (e.g., Tagliabue et al., 2000). If the SNARC and spatial SRC effects share a common underlying mechanism, as the number-line account implies and as Notebaert et al. (2006) argued on the basis of mixed spatial SRC and number-orientation tasks, then the SNARC effect should be influenced as well by the practice SRC mapping. In Experiment 2A, 72 practice trials were used, a number that produces transfer for spatial tasks (e.g., Tagliabue et al., 2000); in Experiment 2B, the number of practice trials was increased to 600.

Experiment 2A

Method

Forty new undergraduate students (20 male; 20 female) from the same subject pool as in Experiment 1 participated. Participants were randomly assigned to two different practice mapping groups: compatible and incompatible SRC mappings.

Apparatus, stimuli, and procedure were identical to those in Experiment 1, except for the practice task, which was the spatial SRC task. The stimulus for the SRC task was a white square (0.8 × 0.8 cm, 0.7° × 0.7°), randomly presented 2.2 cm (2.1°) left or right of a white fixation row *XXX* (0.5 × 0.5 cm, 0.4° × 0.4° for each *X*) on a dark background.

Each trial began with the fixation row, at which participants were instructed to stare. After 500 ms, an imperative stimulus was presented to the left or right of the fixation row and remained until the response was made. When participants made a response with the left or right key, according to instructions, a 500-Hz pitch tone was given for 500 ms as feedback for an incorrect response only. After 1,000 ms, the fixation row for the next trial was presented. Participants performed 12 warm-up trials and 72 trials for the practice session. After performing the parallel SRC task in the practice session, they took a 5-min break and then entered into the transfer session, in which they performed 160 trials of the parity-judgment task.

Results

For the practice SRC task, RT was shorter with the compatible spatial mapping (281 ms) than with the incompatible mapping (332 ms), $F(1, 38) = 13.16$, $p = .0008$, $MSE = 1993$, showing a typical SRC effect. The PE data showed a nonsignificant tendency in the same direction (compatible, 0.14%; incompatible, 0.49%), $F(1, 38) = 1.17$, $p = .287$, $MSE = 1.03$.

For the transfer parity-judgment task, ANOVAs were conducted on the RT and PE data with SNARC compatibility as a within-subject factor and practice mapping and transfer mapping as between-subject factors (see Table 1 for means). For RT, SNARC compatibility was significant, $F(1, 36) = 15.67$, $p = .0003$, $MSE = 471$: A 19-ms small–left/large–right advantage was obtained. The two-way interaction of practice mapping with SNARC compatibility was not significant, $F(1, 36) = 1.12$, $p = .2968$, $MSE = 471$, and the tendency was opposite that predicted by the number line account: The SNARC effect tended to be smaller when practice was with the compatible spatial mapping (14 ms) rather than the incompatible mapping (24.5 ms). A separate comparison showed that the 19-ms overall SNARC effect was not significantly different from the 22-ms effect for the control group that performed only the parity judgment task ($F < 1.0$).

SNARC compatibility interacted with transfer mapping, $F(1, 36) = 7.35$, $p = .0102$, $MSE = 471$, as in Experiment 1. The odd–left/even–right parity mapping showed a nonsignificant 6-ms SNARC effect ($F < 1$), whereas the odd–right/even–left mapping showed a 33-ms SNARC effect, $F(1, 36) = 22.27$, $p < .0001$, $MSE = 471$. No other effect was significant.

Overall PE was 2.35%. Only the effect of SNARC compatibility was significant for PE, $F(1, 36) = 4.90$, $p = .0333$, $MSE = 11.09$, showing a 1.6% SNARC effect.

As for Experiment 1, the SNARC effect for each digit was expressed as dRT (see Figure 2, top panel). For SRC practice-task mappings, the regression lines showed continuous functions of similar slopes. The SNARC effect for the parity-judgment task was evident after practice with compatible ($\text{dRT} = -11.345x + 44.774$; $R^2 = 0.2902$) and incompatible ($\text{dRT} = -13.143x + 57.035$; $R^2 = 0.8516$) spatial mappings. Due to high variability among the odd and even numbers, the slope did not differ significantly from 0 for the compatible practice condition, $t(7) = -1.57$, $p = .168$, but it did for the incompatible practice condition, $t(7) = -5.87$, $p < .01$.

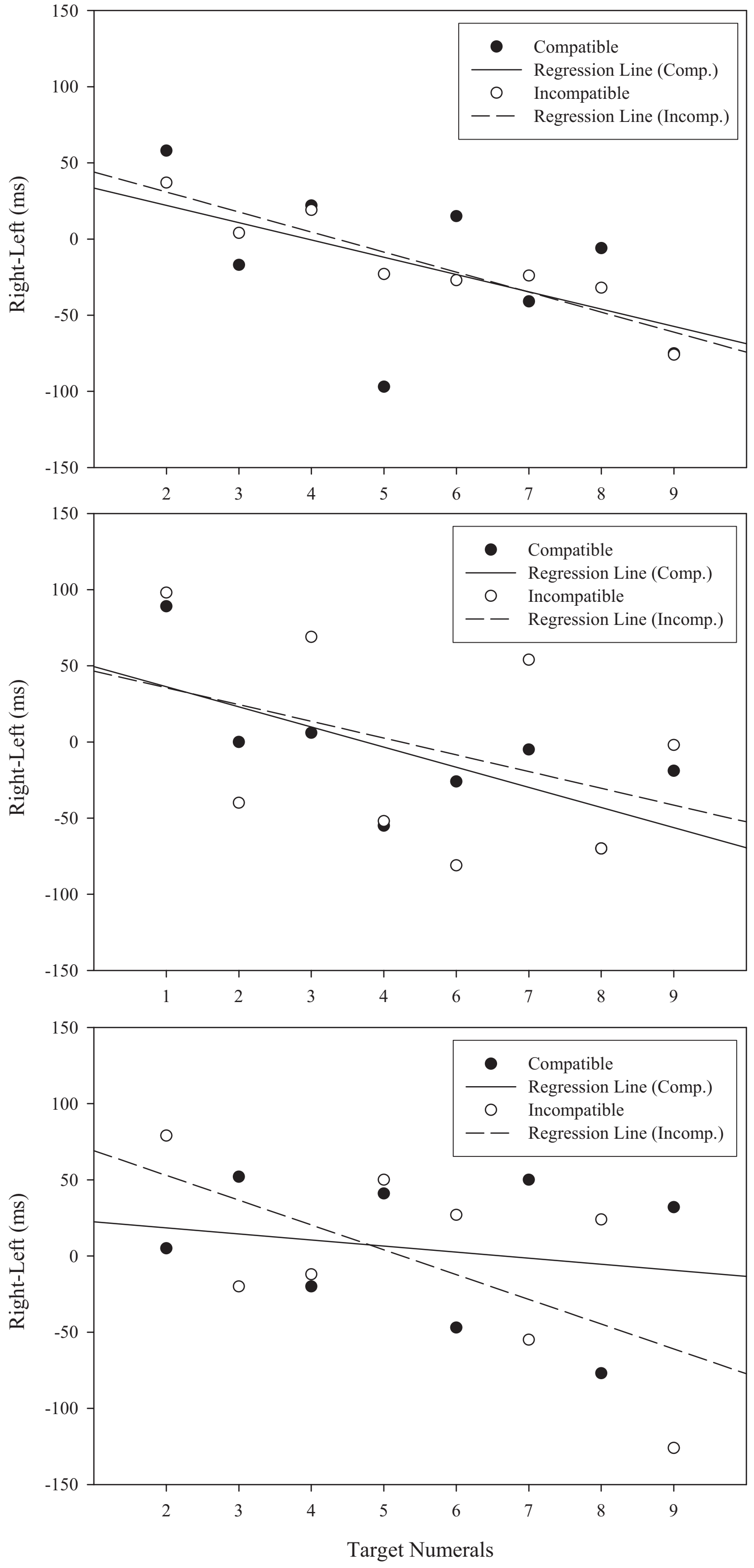

Figure 2. Experiment 2: Difference in reaction time for each number (right response minus left response) with best fitting regression line for the parity-judgment transfer tasks of Experiments 2A (top panel) and 2B (middle panel, stimulus set *1–4* and *5–9*; bottom panel, stimulus set *2–9*).

Experiment 2B

Method

Forty new undergraduates enrolled in the course Brain and Psychology at Korea University participated for credit in partial fulfillment of a course requirement. Half practiced the SRC task with compatible mapping, and half with incompatible mapping. All were right handed and had normal or corrected-to-normal vision.

The apparatus, stimuli, and procedure were identical to those in Experiment 2A, except that the number of practice trials was increased from 72 to 600. For half of the subjects, the digits for the parity-judgment task were *2–9*, as in Experiments 1 and 2A; for the other half, the digits *1*, *2*, *3*, *4*, *6*, *7*, *8*, and *9* were used. This latter set provides a clearer demarcation between the small and large numbers because the digit *5* is omitted.

Results

For the practice SRC task, RT for the compatible SRC mapping (263 ms) was shorter than that for the incompatible SRC mapping (330 ms), $F(1, 38) = 34.99$, $p < .0001$, $MSE = 1283$. For PE, more errors tended to occur for the incompatible trials (0.97%) than compatible trials (0.27%), $F(1, 38) = 14.87$, $p = .0004$, $MSE = 0.33$.

For the transfer parity-judgment task, with the same outlier criteria as previously, 67 trials among 6,400 trials (1.04%) were removed. ANOVAs were conducted on the RT and PE data as in Experiment 2A, with stimulus set as an additional between-subjects factor (see Table 1 for means). RT showed a main effect of SNARC compatibility, $F(1, 32) = 59.37$, $p < .0001$, $MSE = 150$: RT was 21 ms shorter for SNARC compatible trials (472 ms) than for SNARC incompatible trials (493 ms). The interaction between practice mapping and SNARC compatibility was not significant, $F(1, 32) = 2.03$, $p = .164$, $MSE = 150$, but the two-way interaction of SNARC compatibility and transfer mapping, $F(1, 32) = 4.94$, $p = .034$, $MSE = 150$, and the four-way interaction of all variables, $F(1, 32) = 6.21$, $p = .018$, $MSE = 150$, were. To clarify these interactions, we conducted separate ANOVAs for each stimulus set.

For the *2–9* stimulus set used in Experiments 1 and 2A, RT was shorter for the SNARC compatible mapping ($M = 468$ ms) than for the SNARC incompatible mapping ($M = 489$ ms), $F(1, 16) = 30.93$, $p < .0001$, $MSE = 146$. Also, as in those experiments, a two-way interaction of SNARC compatibility and transfer mapping was evident, $F(1, 16) = 8.01$, $p = .012$, $MSE = 146$. The SNARC effect was a nonsignificant 10 ms for the odd–left/even–right parity mapping, $F(1, 16) = 3.72$, $p = .071$, $MSE = 146$, but a significant 32 ms for the odd–right/even–left mapping, $F(1, 16) = 35.22$, $p < .0001$, $MSE = 146$. The only other term to approach significance was the Practice Mapping × SNARC Compatibility interaction, $F(1, 16) = 3.27$, $p = .090$, $MSE = 146$. The tendency was for the SNARC effect to be larger following the incompatible spatial mapping, which is opposite to the predicted direction (see Table 1).

For the new stimulus set of *1–4* and *6–9*, the main effect of SNARC compatibility was significant, $F(1, 16) = 28.50$, $p < .0001$, $MSE = 153$, with RT shorter for SNARC compatible trials ($M = 476$ ms) than for SNARC incompatible trials ($M = 497$ ms). The two-way interaction between practice mapping and transfer mapping was not significant ($F < 1$), and SNARC compatibility did not interact with the practice SRC mapping (see Table 1), $F < 1$, being 20 ms following the compatible mapping and 22 ms following the incompatible mapping. The transfer mapping main effect approximated the .05 level, $F(1, 16) = 4.25$, $p = .055$, $MSE = 4{,}700$: RT was shorter for the odd–left/even–right mapping ($M = 464$ ms) than for the odd–right/even–left mapping ($M = 509$ ms). An advantage for the former mapping has been reported in other studies and is called the linguistic markedness association of response codes (MARC) effect (Nuerk, Iverson, & Willmes, 2004). Also, unlike with the *2–9* stimulus set, parity mapping did not interact with SNARC compatibility, $F < 1$.

Overall error rate was 3.58%. There was a main effect of SNARC compatibility, $F(1, 32) = 33.12$, $p < .0001$, $MSE = 6.70$. PE was smaller for SNARC compatible trials (1.92%) than for SNARC incompatible trials (5.25%). No other term was significant.

As for Experiments 1 and 2A, the SNARC effect for each number was expressed as dRT (see Figure 2, middle and bottom panels). For the *2–9* stimulus set, the regression lines showed negative slopes, although neither was significantly different from 0, $ts(7) = -0.50$ and -1.91, $ps > .10$; after practice with the compatible spatial mapping ($\text{dRT} = -10.583x + 42.917$; $R^2 = .0407$); after practice with the incompatible mapping ($\text{dRT} = -16.274x + 85.381$; $R^2 = .8516$). For the new stimulus set of *1–4* and *6–9*, the regression lines showed similar functions with slightly negative slopes that were not significantly different from 0, $ts(7) = -2.07$ and -1.04, $ps = .084$ and $.339$; after practice with the compatible spatial mapping ($\text{dRT} = -3.976x + 26.369$; $R^2 = .4163$); after practice with the incompatible mapping ($\text{dRT} = -9.150x + 42.75$; $R^2 = .1523$).

Discussion

In Experiment 2A, after 72 practice trials with the spatial SRC task, the SNARC effect did not vary significantly as a function of the practiced spatial mapping. In Experiment 2B, SNARC compatibility again did not interact significantly with mapping of the SRC practice task for either of the two stimulus sets, although the practice amount was increased to 600 trials. For Experiments 2A and 2B combined, the interaction between practice mapping and SNARC effect for RT in the transfer session was nonsignificant, $F(1, 72) = 2.52$, $p = .117$, and the trend was for the SNARC effect to be smaller following practice with a compatible spatial mapping (16 ms) than with an incompatible mapping (24 ms), which is opposite the pattern expected from coding of numbers on a left–right line. It could be argued that 72 practice trials is insufficient for establishing sufficiently strong SC-STM links to transfer to the parity-judgment task. But 600 practice trials should be sufficient because this amount of practice has yielded transfer effects for several variations of the SRC and Simon tasks that do not show transfer after 72 practice trials (Proctor, Yamaguchi, & Vu, 2007; Proctor et al., 2009; Vu, 2007).

The results of Experiment 2 thus imply that the SC-STM links between stimulus locations and responses created when performing the SRC task are not involved in the processing of magnitude information in the subsequent parity-judgment task. That is, the results do not support the argument that a common representation underlies the Simon and SNARC effects. This outcome suggests that the SNARC effect is unlikely to be due to a left–right ordered number magnitude representation, consistent with the results obtained in Mapelli et al.'s (2003) experiment showing no interaction of the Simon effect and the SNARC effect.

Another important result of Experiment 2 is that the two-way interaction of transfer parity mapping and SNARC compatibility was obtained only for the stimulus set *2–9* used in Experiments 1. The stimulus set of *1–4* and *6–9* used for half of the participants in Experiment 2B showed no interaction, which implies that the specific *2–9* stimulus set is the source of the interaction. Moreover, an overall MARC effect (advantage for odd–left/even–right mapping) was evident for the first time in the *1–4* and *6–9* set, suggesting that the MARC effect is also dependent on the specific stimulus set. We discuss these findings in the General Discussion.

Experiment 3

Bae, Cho, and Proctor (2009) established that the mapping used for an orthogonal SRC practice task modulates the Simon effect in a subsequent orthogonal Simon task. Their results showed a larger benefit for the up–right/down–left relation in the Simon task after 72 practice trials with that mapping than after the same amount of practice with the opposite mapping. In Experiment 3, we examined whether the SNARC effect is modulated similarly by the mapping when participants practice an orthogonal SRC task prior to performing the parity-judgment task. Modulation of the SNARC effect by the mapping used for the orthogonal SRC practice task would implicate shared representations for these two tasks, possibly based on code polarity. Specifically, transfer would be expected if practice establishes SC-STM links between code polarities because up is coded as positive polarity and down as negative polarity. In the transfer session, large, which is coded as positive polarity, and small, which is coded as negative polarity, would be expected to activate the responses to which up and down were associated in the practice session.

Method

Participants. Initially, 40 new undergraduates (18 male; 22 female) enrolled in an Experimental Psychology course at Korea University participated. Their data showed a small interaction of SNARC compatibility with practice mapping. To ensure reliability of the interaction, we tested an additional 40 students (19 male; 21 female) enrolled in Fundamentals of Psychology at Korea University and 40 students (20 male; 20 female) enrolled in Introductory Psychology at Purdue University. All participants received credits toward a course requirement. Half in each sample practiced with up–right/down–left mapping, and half with up–left/down–right mapping. All were right handed and had normal or corrected-to-normal vision.

Apparatus, stimuli and procedure. The only difference from Experiment 2A was the practice task. Participants practiced 72 trials of an orthogonal SRC task: Left–right responses were made to the stimulus location, which was randomly above or below the fixation row. The size of the target stimulus (a white square, 0.8 cm × 0.8 cm, 0.7° × 0.7°) and the distance between fixation row and stimulus (2.2 cm, 2.1°) were identical to those in Experiment 2A.

Results

Practice orthogonal SRC task. Two-factor ANOVAs were performed on the RT and PE data with the variables of sample (Korean 1, Korean 2, American) and practice mapping. PE showed no significant effects (Fs ≤ 1.21, ps $> .30$). For RT, sample showed a main effect, $F(2, 114) = 4.36$, $p = .015$, $MSE = 3{,}947$, with shorter RT for the Korean samples ($M = 308$ ms) than for the American sample ($M = 342$ ms). There was no significant difference between mappings, and mapping did not interact with sample, Fs < 1. Nonsignificance of the up–right/down–left mapping advantage in between-subject designs is common because the effect size is small. For example, in Bae et al.'s (2009) study examining transfer to the Simon task, the up–right/down–left advantage was significant only when data were combined across several experiments.

Transfer parity-judgment task. ANOVAs were conducted on RT and PE with SNARC compatibility (within subjects), practice mapping, transfer mapping, and sample as factors. The means for the conditions, collapsed across sample, are shown in Table 1.

For RT, sample showed a main effect, $F(2, 108) = 6.75$, $p < .001$, $MSE = 11{,}769$: RT was less for the Korean samples ($M = 487$ ms) than for the American sample ($M = 519$ ms). This 32-ms difference is similar to that for the practice orthogonal SRC task, implying that it is a property of the subject samples or apparatuses and not specific to the task. SNARC compatibility was significant, $F(1, 108) = 101.95$, $p < .0001$, $MSE = 328$: RT was 24 ms shorter for the pairings of small–left/large–right than of small–right/large–left. This SNARC effect interacted with practice mapping (see Table 1), $F(1, 108) = 6.75$, $p = .010$, $MSE = 327$, being 12 ms larger after practice with the up–right/down–left mapping (30 ms), $F(1, 108) = 80.76$, $p < .0001$, $MSE = 327$, than with the up–left/down–right mapping (18 ms), $F(1, 108) = 28.17$, $p < .0001$, $MSE = 327$. The former effect was 8 ms larger than the 22-ms effect of the control condition and the latter was 4 ms smaller, but neither difference was significant, Fs$(1, 76) \leq 1.62$, ps $\geq .207$, $MSEs = 269$ and 355.

SNARC compatibility again interacted with transfer mapping, $F(1, 108) = 13.96$, $p < .001$, $MSE = 327$. The SNARC effect was smaller with odd–left/even–right mapping (15 ms), $F(1, 108) = 20.273$, $p < .0001$, than with odd–right/even–left mapping (32 ms), $F(1, 108) = 90.91$, $p < .0001$. These variables also entered into a three-way interaction with sample, $F(2, 108) = 3.59$, $p = .031$, $MSE = 32$. The difference in SNARC effect for the two transfer mappings was evident for the Korean samples, $F(1, 76) = 28.09$, $p < .0001$, but not the American sample ($F < 1.0$).

Overall PE was 3.17%. There was a main effect of SNARC compatibility, $F(1, 108) = 51.45$, $p < .0001$, $MSE = 11.04$. A 3.1% SNARC effect was obtained. SNARC compatibility entered into a two-way interaction with sample and a three-way interaction of those variables with transfer mapping, Fs$(2, 108) = 3.36$ and 3.70, ps $= .038$ and .028, $MSE = 11.040$. The SNARC effect for PE was smaller for the first Korean sample (1.67%) than for the second Korean sample (4.39%) and the American sample (3.17%), and these differences were more evident with the up–left/down–right mapping than with the up–right/down–left mapping.

The relation between dRT and digit magnitude (see Figure 3) was described by the function $\text{dRT} = -15.077x + 73.718$, $R^2 = 0.8448$, after practice with up–right/down–left mapping; and

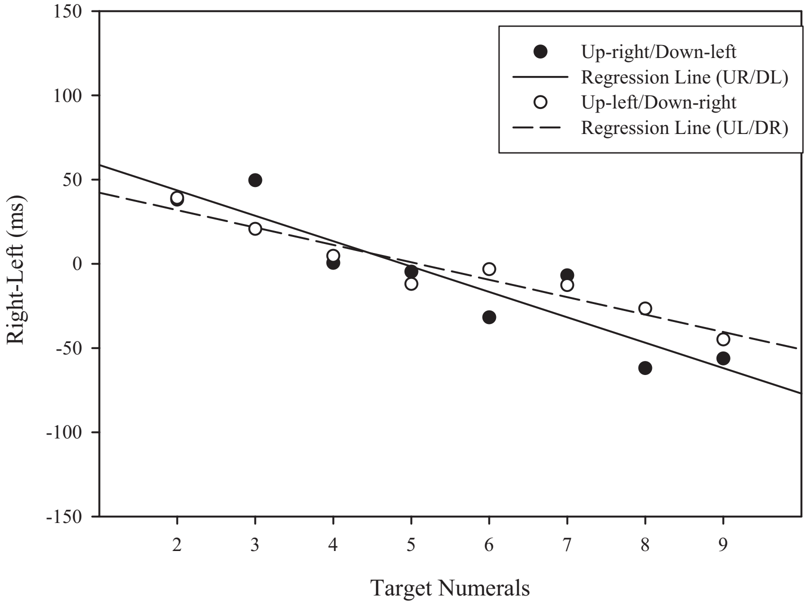

Figure 3. Experiment 3: Difference in reaction time for each number (right response minus left response) with best fitting regression line for the parity-judgment transfer task of Experiment 3.

dRT = –10.338x + 52.474, R^2 = 0.9210, after practice with up–left/down–right mapping. The slopes for both functions were different from 0, ts(7) = –5.71 and −8.36, ps < . 01, a sign of the SNARC effect. The difference in slopes of 4.749 ms leads to an estimated difference in SNARC effect sizes of 33 ms, though the difference in slopes was not significant, $F(1, 13) = 1.64$, $p = .222$, $MSE = 182$. The power is much less for the slope analysis than for the ANOVA (error degrees of freedom of 13 and 108, respectively), which is likely the reason why the slope analysis does not show a significant difference in SNARC effects but the ANOVA does.

Discussion

The SNARC effect was 12 ms smaller after practice with the up–left/down–right mapping than with the up–right/down–left mapping. This difference suggests that the digits in the parity-judgment task activate representations that are shared with the orthogonal SRC task. An interpretation of the transfer results in terms of polarity coding (e.g., Proctor & Cho, 2006) is that when performing the orthogonal SRC task, SC-STM links of positive (up) and negative (down) stimulus polarities with positive (right) and negative (left) response polarities are formed in accord with the mapping. The number stimuli in the parity-judgment task continue to produce activation through these SC-STM links of polarity codes, producing the observed influence on the SNARC effect.

One possibility is that the SC-STM links are activated by parity codes for small (negative) and large (positive) numbers, leading to a reduced SNARC effect when the established SC-STM links are between stimulus and response codes of opposite polarity. In agreement with this view, the dRT functions showed a numerically larger slope between following the polarity compatible up–right/down–left practice mapping than following the incompatible up–left/down–right mapping.

The up–left/down–right practice mapping should also establish SC-STM links of the up stimulus code with the left response and the down stimulus code with the right response. In fact, we favored an explanation of transfer from the orthogonal SRC task to the orthogonal Simon task in terms of these SC-STM links between up and left and down and right (Bae et al., 2009). Our reasoning was that the instructions for the practice task were in terms of stimulus locations and responses and that these same spatial relations (up and down responses; left and right responses) remained present in the transfer task. A similar account applied to the results of Experiment 3 would say that large numbers are coded as up and small numbers as down, producing activation through the SC-STM links established by the practice task. This alternative account in terms of links between specific locations cannot be ruled out entirely. However, the lack of transfer in Experiment 2 from the parallel spatial SRC task to the parity-judgment task seems to argue against such an account. That is, the spatial explanation of the SNARC effect emphasizes coding of digits along a horizontal number line. This explanation implies, counter to the results, that spatial associations involving the horizontal dimension (which also overlaps with the response dimension for the parity-judgment task) should produce more transfer than spatial associations involving the vertical stimulus dimension.

Although we have interpreted transfer in terms of shared representations, transfer can also occur if a general rule or procedure is learned that can be applied to the transfer task. Vu (2007) had participants practice an incompatible mapping of stimuli and responses along one spatial dimension (vertical or horizontal) and transfer to a Simon task for which the stimuli and responses varied along the orthogonal dimension (horizontal or vertical). Between-dimension transfer was not evident after 72 practice trials but was after 600 practice trials. Vu attributed the transfer after extended practice to learning of a "respond opposite" procedure that was applicable even when the dimension along which the stimuli and responses varied was changed. Note, though, that in our Experiment 3, only the small number of trials was used, which did not show evidence of such learning in Vu's study. Moreover, there is no obvious rule-like relation for an orthogonal S-R mapping that could be applied to the parity-judgment task.

General Discussion

Primary Outcomes

The present study established that the SNARC effect in a transfer parity-judgment task is influenced by the S-R mapping used for a prior practice task. In Experiment 1, the SNARC effect for the parity-judgment task increased when a prior magnitude-judgment task used a small–left/large–right magnitude mapping but decreased when it used a small–right/large–left mapping. This influence of practice magnitude mapping suggests that in the parity-judgment task the target number activates a response code through the MC-STM links created during the prior practice trials, even though magnitude is no longer relevant. Thus, the mapping of number magnitude yields a transfer effect much like that of stimulus location when the dimension is changed to irrelevant in the transfer task, and this transfer effect for number magnitude is at least as large as that for spatial location (e.g., Tagliabue et al., 2000; Vu, Proctor, & Urcuioli, 2003).

When a spatial SRC task was practiced in Experiment 2A, the magnitude of the SNARC effect in the transfer parity-judgment task remained constant regardless of whether participants practiced the SRC task with compatible or incompatible mapping for 72 trials. When the number of practice trials was increased to 600 in Experiment 2B, the SNARC effect still was not modulated by the practiced spatial mapping. The results of Experiments 2A and 2B thus imply that the SC-STM links created for the spatial SRC task, which are associations between the left–right stimulus codes and their assigned left–right response codes, did not activate the response codes in the transfer parity-judgment task. The lack of effect of the SC-STM spatial S-R links implies that the digit stimuli in the parity-judgment task were not coded as left and right along a number line, because such coding should have produced activation through the SC-STM links.

The implication of Experiments 2A and 2B that the spatial SRC and parity-judgment tasks do not share spatial representations is counter to the conclusion reached by Notebaert et al. (2006), using a method in which trials of an SRC task were mixed with trials of a task in which digits were to be classified as upright or italicized orientation. In their Experiment 2, the SNARC effect was influenced by the mapping for the mixed SRC task, being 40 ms when it was compatible and –20 ms when it was incompatible. The tasks used in our Experiment 2 and Notebaert et al.'s Experiment 2 differ in several ways (e.g., the digits were judged according to parity in our experiment but orientation in theirs). However, the crucial difference likely is that the spatial mapping was not in effect when our participants performed the digit classification task but was when their participants did. In Notebaert et al.'s study, the relevance of stimulus location and spatial mapping while performing the digit-classification task could have induced participants to code number magnitude spatially, whereas they would not have done so otherwise.

Though the SNARC effect in the transfer task was not modulated by the practiced left–right spatial mapping in our Experiment 2, it was modulated by the practiced mapping of up–down stimuli to left–right responses in Experiment 3. The SNARC effect was smaller when the orthogonal SRC practice task was performed with up–left/down–right mapping than with up–right/down–left mapping. This result shows that it is possible to obtain transfer from a spatial SRC task that influences the size of the SNARC effect in the parity-judgment task. In this case, though, the STM links established in practice would not have been of left–right stimulus locations to the left–right responses. The transfer from the orthogonal SRC task may have been based on SC-STM links for the vertical stimulus dimension (see Bae et al., 2009), which would imply that the digits in the transfer task were being coded along a vertical number line.

We think it more likely that the STM links producing transfer from the orthogonal SRC task were between the polarities of the stimulus and response codes. Large magnitude numbers of positive polarity would tend to activate the response to which the up stimulus position of positive polarity was associated in the practice task, and small magnitude numbers of negative polarity would tend to activate the response to which the down stimulus position of negative polarity was associated, modulating the SNARC effect. If the STM links producing transfer from the orthogonal SRC task to the parity-judgment task in Experiment 3 were of code polarities, why was transfer from the parallel SRC task not also evident in Experiment 2? At present, there is no evidence that code polarity contributes to SRC effects obtained for tasks in which stimulus and response positions correspond along the same dimension. Spatial correspondence may be so salient in that case that polarity correspondence is overridden (see Heister et al., 1990, for a similar idea of a hierarchy of coding relations).

Santens and Gevers (2008) reported results that also implicate polarity correspondence in the SNARC effect. Their participants performed a magnitude-judgment task for which the responses were unimanual movements of an index finger to one of two response keys, both located to the left of the home key for some participants and both to the right for others. A SNARC effect was observed for which the mapping of small numbers to the close key and large numbers to the far key yielded better performance than the opposite mapping, regardless of whether the movement direction was to the left or right. Santens and Gevers concluded,

> Like the model by Gevers, Verguts, et al. (2006) and the account by Proctor and Cho (2006), the present study argues in favor of an intermediate categorization of numbers as relatively small (negative polarity) or relatively large (positive polarity) in order to explain the SNARC effect. (p. 269)

Previous studies have also reported a MARC effect, shorter RT for odd–left/even–right mapping than for the opposite mapping, which can also be attributed to polarity correspondence (Cho & Proctor, 2007). In the parity-judgment task, even and right tend to be coded as positive polarity and odd and left as negative polarity because of linguistic markedness (Lyons, 1977). When the parity-judgment task is performed with odd–left/even–right mapping, the two positive polarity codes are mapped to each other, as are the two negative polarity codes, yielding polarity correspondence. When the task is performed with odd–right/even–left mapping, the mappings of code polarities are crossed, yielding polarity noncorrespondence.

An overall MARC effect was evident only with the digit set of *1–4* and *6–9* used for half of the participants in Experiment 2B. The *2–9* stimulus set used in all other conditions never showed an overall MARC effect, even in the control experiment where the effect was 23 ms but with $F < 1.0$. Regardless of whether there is a small MARC effect for the *2–9* stimulus set, the results suggest that the effect is more apparent for the *1–4* and *6–9* set, which differed in having *1*, an odd number, as the lowest value, and a gap of one digit separating the small and large numbers. Comparison of the panels in Figure 2 for the two stimulus sets in Experiment 2B indicates that the digit *1* produced a larger MARC effect (98 ms) than any other digit, regardless of practice mapping. For the remaining digits, the MARC effect averaged < 10 ms, indicating that the digit *1* was the major determinant of the large overall MARC effect for the *1–4* and *6–9* stimulus set.

In all experiments, the *2–9* stimulus set showed a two-way interaction of Transfer Parity Mapping × SNARC Compatibility: The SNARC effect was larger with the MARC incompatible odd–right/even–left mapping than with the odd–left/even–right mapping. The SNARC effects for the respective mappings were 23 ms and −4 ms in Experiment 1, 33 ms and 6 ms in Experiment 2A, and 32 ms and 15 ms in Experiment 3. The interaction was significant regardless of which task was performed for practice, and whether the practice-task mapping modulated the SNARC effect. The two exceptions for which the interaction was not obtained were with the *1–4/6–9* set in Experiment 2B and for the

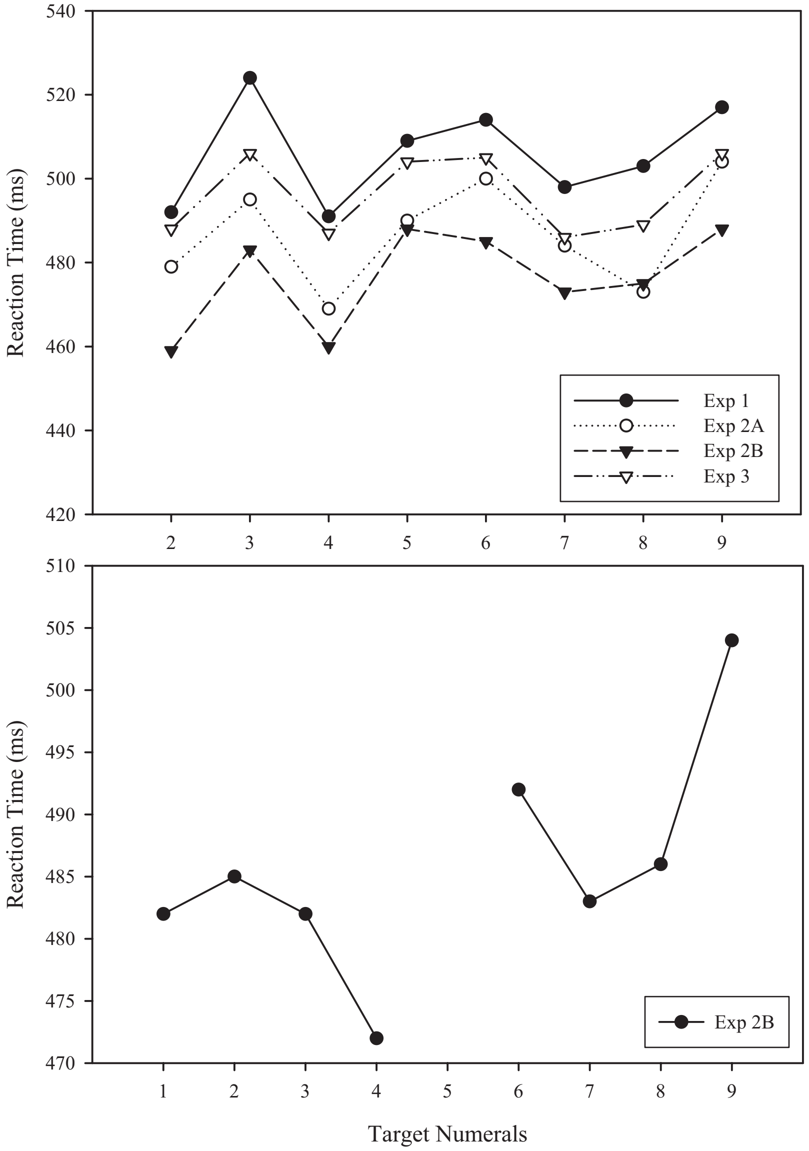

Figure 4. Mean reaction time (in milliseconds) as a function of target numeral for the *2–9* number set in Experiments 1, 2A, 2B, and 3 (top panel) and the *1–4* and *5–9* set in Experiment 2B (bottom panel).

American sample with the *2–9* set in Experiment 3, suggesting that a property of the *2–9* stimulus set that may be specific to Koreans is responsible for the interaction.

It is important to note that responses were faster for the digits *2* and *4* than for the other numerals when the RT data were reanalyzed as a function of the target numeral, $F(7, 735) = 14.35$, $p < .0001$, $MSE = 1{,}215$ (Figure 4, top panel). This response pattern was not evident for the condition in Experiment 2B, in which the set of small numbers included *1* and not *5* (Figure 4, bottom panel). As seen in Table 2, different responses were made to different numerals in different combinations of SNARC and parity compatibilities in Experiments 1, 2A, and 3. For example, for SNARC compatibility with the odd–left/even–right mapping, the right response was made to *6* and *8* and the left response to *3* and *5*. For SNARC incompatibility with the same mapping, the right response was made to *2* and *4* and the left response to *7* and *9*. Likewise, for SNARC compatibility with the odd–right/even–left mapping, the right response was made to *7* and *9* and the left response to *2* and *4*. For SNARC incompatibility with the same mapping, the right response was made to *3* and *5* and the left response to *6* and *8*. Because the responses to *2* and *4* were faster than to the other numerals, regardless of whether the mapping was odd–left/even–right or odd–right/even–left, mean RT was shorter for SNARC incompatibility than for SNARC compatibility when participants performed the parity-judgment task with the odd–left/even–right mapping, whereas the opposite pattern was obtained when they performed with the odd–right/even–left mapping. One possible explanation for the relatively fast responses to *2* and *4* is that the semantic characteristic of the target number is important for the parity-judgment task. According to Shepard, Kilpatrick, and Cunningham (1975), within the even category, the powers of *2* form a salient mental category. So, *2*, *4*, and *8* are classified faster than other even numbers. In line with the prediction of this account, the responses to *6* were the slowest among the even numbers in our experiments (see Figure 4). Alternatively, participants may code the number set as the progression *2*, *4*, *6*, *8*, versus *1*, *3*, *5*, *9*, when *2* is the smallest digit.

Conclusion

The present study demonstrates that transfer of the mappings from a task in which digit magnitude is irrelevant transfers to influence the SNARC effect in a task for which magnitude is irrelevant, much as occurs for mappings of spatial locations. However, the SNARC effect in the transfer task was unaffected by practice with a mapping of left–right locations to responses, inconsistent with the widely accepted view that the SNARC effect is a Simon-type spatial correspondence effect based on a left–right ordered mental number representation. The SNARC effect was, however, modulated by the mapping of an orthogonal SRC task, consistent with recent proposals that the effect is due at least in part to correspondence of categorical code polarities (Gevers, Verguts, et al., 2006; Proctor & Cho, 2006).

Table 2
Target Numerals as a Function of SNARC Compatibility, Transfer Parity Mapping, and Response in Experiments 1, 2A, and 3

	Transfer mapping			
	Odd–left/ even–right		Odd–right/ even–left	
SNARC compatibility	Left	Right	Left	Right
Compatible	3, 5	6, 8	2, 4	7, 9
Incompatible	7, 9	2, 4	6, 8	3, 5

Note. SNARC = spatial numerical association of response codes.

References

Altmann, E. M., & Gray, W. D. (2008). An integrated model of cognitive control in task switching. *Psychological Review, 115,* 602–639.

Bächtold, D., Baumüller, M., & Brugger, P. (1998). Stimulus–response compatibility in representational space. *Neuropsychologia, 36,* 731–735.

Bae, G. Y., Cho, Y. S., & Proctor, R. W. (2009). Transfer of orthogonal stimulus–response mappings to an orthogonal Simon task. *Quarterly Journal of Experimental Psychology, 62,* 746–765.

Barber, P., & O'Leary, M. (1997). The relevance of salience: Towards an activation account of irrelevant stimulus-response compatibility effects. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus–response compatibility* (pp. 135–172). Amsterdam, the Netherlands: North-Holland.

Cho, Y. S., & Proctor, R. W. (2002). Influences of hand posture and hand position on compatibility effects for up–down stimuli mapped to left–right responses: Evidence for a hand referent hypothesis. *Perception & Psychophysics, 64,* 1301–1315.

Cho, Y. S., & Proctor, R. W. (2003). Stimulus and response representation underlying orthogonal stimulus–response compatibility effects. *Psychonomic Bulletin & Review, 10,* 45–73.

Cho, Y. S., & Proctor, R. W. (2007). When is an odd number not odd? Influence of task rule on the MARC effect for numeric classification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 832–842.

Cho, Y. S., Proctor, R. W., & Yamaguchi, M. (2008). Influence of response position and hand posture on the orthogonal Simon effect. *Quarterly Journal of Experimental Psychology, 61,* 1020–1035.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, L. (2001). DDC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108,* 204–256.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General, 122,* 371–396.

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus–response correspondence. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 731–750.

Fias, W. (2001). Two routes for the processing of verbal number: Evidence from the SNARC effect. *Psychological Research, 65,* 250–259.

Fias, W., Brysbaert, M., Geypens, F., & d'Ydewalle, G. (1996). The importance of magnitude information in numerical processing: Evidence from the SNARC effect. *Mathematical Cognition, 2,* 95–110.

Fias, W., Lauwereyns, J., & Lammertyn, J. (2001). Irrelevant digits affect feature-based attention depending on the overlap of neural circuits. *Cognitive Brain Research, 12,* 415–423.

Gevers, W., Caessens, B., & Fias, W. (2005). Towards a common processing architecture underlying Simon and SNARC effects. *European Journal of Cognitive Psychology, 17,* 659–673.

Gevers, W., Lammertyn, J., Notebaert, W., Verguts, T., & Fias, W. (2006). Automatic response activation of implicit spatial information: Evidence from the SNARC effect. *Acta Psychologica, 122,* 221–233.

Gevers, W., Ratinckx, E., De Baene, W., & Fias, W. (2006). Further evidence that the SNARC effect is processed along a dual-route architecture. *Experimental Psychology, 53,* 58–68.

Gevers, W., Reynvoet, B., & Fias, W. (2003). The mental representation of ordinal sequence is spatially organized. *Cognition, 87,* B87–B95.

Gevers, W., Verguts, T., Reynvoet, B., Caessens, B., & Fias, W. (2006). Numbers and space: A computational model of the SNARC effect. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 32–44.

Heister, G., Schroeder-Heister, P., & Ehrenstein, W. H. (1990). Spatial coding and spatio-anatomical mapping: Evidence for a hierarchical model of spatial stimulus-response compatibility. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 117–143). Amsterdam, the Netherlands: North-Holland.

Ito, Y., & Hatta, T. (2004). Spatial structure of quantitative representation of numbers: Evidence from the SNARC effect. *Memory & Cognition, 32,* 662–673.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility: A model and taxonomy. *Psychological Review, 97,* 253–270.

Kosslyn, S. M. (1994). *Image and brain: The resolution of the imagery debate.* Cambridge, MA: MIT Press.

Lyons, J. (1977). *Semantics* (Vol. 1). London, England: Cambridge University Press.

Mapelli, D., Rusconi, E., & Umiltà, C. (2003). The SNARC effect: An instance of the Simon effect? *Cognition, 88,* B1–B10.

Marble, J. G., & Proctor, R. W. (2000). Mixing location-relevant and location-irrelevant choice–reaction tasks: Influences of location mapping on the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 1515–1533.

Michaels, C. F. (1989). S–R compatibilities depend on eccentricity of responding hand. *Quarterly Journal of Experimental Psychology, 41*A, 262–272.

Michaels, C. F., & Schilder, S. (1991). Stimulus–response compatibilities between vertically oriented stimuli and horizontally oriented responses: The effects of hand position and posture. *Perception & Psychophysics, 49,* 342–348.

Nishimura, A., & Yokosawa, K. (2006). Orthogonal stimulus–response compatibility effects emerge even when the stimulus position is task-irrelevant. *Quarterly Journal of Experimental Psychology, 59,* 1021–1032.

Notebaert, W., Gevers, W., Verguts, T., & Fias, W. (2006). Shared spatial representation of numbers and space: The reversal of the SNARC and the Simon effects. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 1197–1207.

Nuerk, H.-C., Iverson, W., & Willmes, K. (2004). Notational modulation of the SNARC and the MARC (linguistic markedness of response codes) effect. *Quarterly Journal of Experimental Psychology, 57,* 835–863.

Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin, 132,* 416–442.

Proctor, R. W., & Lu, C. H. (1999). Processing irrelevant location information: Practice and transfer effects in choice–reaction tasks. *Memory & Cognition, 27,* 63–77.

Proctor, R. W., Marble, J. G., & Vu, K.-P. L. (2000). Mixing incompatibly mapped location-relevant trials with location-irrelevant trials: Effects of stimulus mode on the reverse Simon effect. *Psychological Research, 64,* 11–24.

Proctor, R. W., & Vu, K. P. L. (2006). *Stimulus–response compatibility principles: Data, theory, and application*. Boca Raton, FL; CRC Press.

Proctor, R. W., Yamaguchi, M., & Vu, K.-P. L. (2007). Transfer of noncorresponding spatial associations to the auditory Simon task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 245–253.

Proctor, R. W., Yamaguchi, M., Zhang, Y., & Vu, K.-P. L. (2009). Influence of visual stimulus mode on transfer of acquired spatial associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 434–445.

Rubichi, S., Vu, K.-P. L., Nicoletti, R., & Proctor, R. W. (2006). Spatial coding in two dimensions. *Psychonomic Bulletin & Review, 13,* 201–216.

Santens, S., & Gevers, W. (2008). The SNARC effect does not imply a mental number line. *Cognition, 108,* 263–270.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's guide.* Pittsburgh, PA: Psychology Software Tools.

Shepard, R. N., Kilpatrick, D. W., & Cunningham, J. P. (1975). The internal representation of numbers. *Cognitive Psychology, 7,* 82–138.

Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 31–86). Amsterdam, the Netherlands: North-Holland.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donder's method. *Acta Psychologica, 30,* 276–315.

Tagliabue, M., Zorzi, M., Umiltà, C., & Bassignani, F. (2000). The role of long-term-memory and short-term-memory links in the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 648–670.

Verguts, T., Fias, W., & Stevens, M. (2005). A model of exact small-number representation. *Psychonomic Bulletin & Review, 12,* 66–80.

Vu, K. P. L. (2007). Influence on the Simon effect of prior practice with spatial incompatible mappings: Transfer within and between horizontal and vertical dimension. *Memory & Cognition, 35,* 1463–1471.

Vu, K.-P. L., Proctor, R. W., & Urcuioli, P. (2003). Transfer effects of incompatible location-relevant mappings on subsequent visual or auditory Simon tasks. *Memory & Cognition, 31,* 1146–1152.

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