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Interaction between Spatial Compatibility and the SNARC effect*

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When responding to numerals with left-right keypresses, performance is better for pairings of small numbers to left responses and large numbers to right responses than for the opposite pairings. Two accounts have been proposed to explain this Spatial Numerical Association of Response Code (SNARC) effect: the horizontal number line account which ascribes the SNARC effect to numbers coded as left or right and the polarity correspondence account which attributes it to the magnitude information being coded as a positive or negative polarity. This study examined whether the SNARC effect is due to the spatial correspondence between the number location on the number line and the response location, or to the correspondence between the polarity codes of the number magnitudes and response locations. When participants responded to the magnitude of an Arabic numeral presented at the left or right to fixation in Experiment 1, the SNARC effect was constant regardless of spatial correspondence between the stimulus and response locations. In contrast, when the numeral was presented above or below fixation in Experiment 2, the SNARC effect was smaller for the up-left/down-right pairings than for the up-right/down-left pairings. These results support a view that polarity correspondence contributes to the SNARC effect.

Key words : SNARC effect, Simon effect, orthogonal Simon effect, SRC effects, Polarity correspondence

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When people make judgments about the magnitude of a centrally presented numeral, their performance is better when they respond with a left key to small numbers and a right key to large numbers than when they respond with the opposite pairings. This “small-left/large-right” advantage is called the *Spatial Numerical Association of Response Code* (SNARC) effect (Dehaene, Bossini, & Giraux, 1993). The SNARC effect occurs regardless of whether the number magnitude information is task-relevant (magnitude judgment) or completely task-irrelevant, such as a parity discrimination task or number orientation judgment task (Fias, Lauwereyns, & Lammertyn, 2001). Also, the SNARC effect can be obtained not only with manual responses, but also oculomotor responses (Fischer, Warlop, Hill, & Fias, 2004; Schwarz & Keus, 2004).

The most widely accepted explanation for the SNARC effect is the horizontal number line account, emphasizing how numbers are represented in the mind. According to this account, the magnitude of numbers is mentally represented in a spatial manner, such as a left-to-right ordered mental number line, where small numbers are located on the left side and large numbers on the right side (Gevers, Reynovet, & Fias, 2003). The horizontal number line account argues that, because the implicit location of small (large) numbers on the mental number line spatially corresponds to the left (right) response location, performance with “small-left/large-right” pairings is better than with “small-right/large-left” pairings.

If the SNARC effect is due to the correspondence between the left or right location of the number on the mental number line and the location of the left or right response, the SNARC effect seems to be closely related to the *Stimulus Response Compatibility* (SRC) effect. The SRC effect occurs when participants make spatial responses to the stimulus location. For example, when a left or right bimanual response is made to horizontally arrayed stimulus set, better performance is obtained when the left response is made to the left stimulus and the right response to the right stimulus (see Proctor & Vu, 2006). This spatial correspondence effect also occurs when stimulus location is irrelevant to response selection. For example, when participants are to respond to the color of the stimulus, responses are faster and more accurate when the stimulus location corresponds to the response location than when it does not. This phenomenon is called the *Simon effect* (e.g., Hommel & Prinz, 1997). Thus, if the SNARC effect is due to the correspondence effect between implicit number location and the response location, the SNARC effect can be regarded as a version of the Simon effect.

Several studies have addressed the question of the common underlying architecture between the SNARC effect and the SRC effect (Mapelli, Rusconi, & Umiltà, 2003; Notebaert, Gevers, Verguts, & Fias, 2006; Gevers Caessens, & Fias, 2005). For example, Notebaert et al.'s (2006) Experiment 2, in which participants performed the parallel SRC and number orientation judgment tasks within a task block in a random order, showed a SNARC effect when the mapping for the SRC task was compatible but a reversed SNARC effect when it was incompatible. This interaction between the spatial SRC and the SNARC compatibility implied that the SNARC effect has a common underlying architecture with the SRC effect, which is caused by the spatial correspondence between the implicit number location on the left-to-right ordered mental number line and response location.

In addition, Gevers et al. (2005) also provided evidence for the idea that the SNARC effect is due to the numbers being coded along a horizontal dimension. They presented a target number to the left or right of a fixation point, and participants were to respond to the number parity and ignore its location. Results showed that the Simon effect was more evident for the SNARC-compatible trials than SNARC-incompatible trials at fast RT bins, even though the Simon effect disappeared at slow RT bins on both types of trials. According to Gevers et al., the spatial codes associated with the number's location are immediately formed after the onset of presentation of the number but the spatial codes associated with the number magnitude are formed at some later point in time. However, because the spatial codes associated with the number location decay or are actively suppressed, the Simon effect decreases as RT increases. Thus, for Simon-compatible trials, the SNARC effect is enhanced by the spatial codes associated with the number location when responses are fast. However, the SNARC effect disappears when responses are delayed because the spatial codes associated with the number location are suppressed. Also, for the Simon-incompatible trial, the SNARC effect is less evident because of the spatial codes associated with the number location when responses are fast and no SNARC effect when responses are delayed.

However, Mapelli et al. (2003), in a similar experiment that differed mainly in manipulating the mapping for the parity-judgment task between rather than within subjects, showed that the Simon and SNARC effects are due to different processing mechanisms. They found no interaction of the Simon and SNARC effects, even though both effects were significant. More importantly, these two effects showed different temporal dynamics. That is, the size of the Simon effect decreased as RT increased, whereas the size of the SNARC effect increased as RT increased. Based on these results, the authors concluded that the SNARC effect is not a mere instance of the Simon effect, indicating that the SNARC and Simon effects have different underlying processing mechanisms.

Recently, an alternative account, the polarity correspondence principle, has been proposed to explain the SNARC effect (Proctor & Cho, 2006). This principle assumes that the stimulus and response alternatives in binary classification tasks are coded as + or - polarity, and responses are faster when stimulus and response polarity codes correspond than when they do not. For example, when up-down stimuli are mapped to left-right responses, performance with "up-right/down-left" mapping is usually better than with the opposite mapping (Cho & Proctor, 2003). This phenomenon is called the *orthogonal SRC effect*. This orthogonal SRC effect also occurs when the stimulus location is task-irrelevant, which is called the *orthogonal Simon effect* (Cho, Proctor, & Yamaguchi, 2008; Nishimura & Yokosawa, 2006). According to the polarity correspondence principle, these "up-right/down-left" advantages are due to "up" and "right" being coded as + polarity and "down" and "left" as - polarity (Proctor & Cho, 2006).

The polarity correspondence principle proposes that the SNARC effect occurs because "small" number and "left" response are coded as "—" polarity, and "large" number and "right" response are coded as "+". This possibility was tested by Bae et al. (2009) using the transfer paradigm. Specifically, in Bae et al.'s Experiment 3, in which participants performed the parity judgment task after practicing the orthogonal SRC task with "up-right/down-left" or "up-left/down-right" mapping for 72 trials, a significant 28 ms SNARC effect was obtained when they practiced the orthogonal SRC task with up-right/down-left mapping, but it was reduced to a significant 13 ms SNARC effect when they practiced the task with up-left/down-right mapping. This interaction between orthogonal SRC mapping and the SNARC effect implies that the SNARC effect has a common underlying mechanism with the orthogonal SRC task which depends on the polarity correspondence between stimulus and response codes.

Interestingly, the pattern of the temporal dynamics of the SNARC effect is similar to that of the orthogonal SRC. It has been reported that the orthogonal SRC effect increases with increasing RT (Adam, Boon, Paas & Umiltà, 1998; Cho & Proctor, 2001). According to Cho and Proctor, because a period of time is required for the polarity codes to form, the orthogonal SRC effect becomes more evident in slow responses. Likewise, the SNARC effect tended to increase with RT (Gevers et al. 2005; Mapelli et al. 2003; see also Cho & Proctor, 2011). Mapelli et al. suggested that, because additional processing is required for accessing number's magnitude information, the SNARC effect is larger at with increasing RT. This similar pattern provides an additional possibility that the SNARC effect shares a common underlying mechanism with the orthogonal SRC effect.

The present study

Even though Gevers et al. (2005) and Mapelli et al. (2003) conducted similar experiments, the two studies provided different patterns of results. Gevers et al. found an interactive effect of the SNARC compatibility with the Simon compatibility, whereas Mapelli et al. showed an addtive effect between them. The aim of the present study was to examine the underlying mechanism of the SNARC effect by using the additive factor logic (Sternberg, 1969) once again to resolve this disparity. That is, if the SNARC effect and the Simon effect (or orthogonal Simon effect) are due to the same underlying mechanism, the two effects should interact with one another (Mapelli et al., 2003). Specifically, the present study focused on whether the SNARC effect is caused by the spatial correspondence between the implicit left or right location of the number on the mental number line representation and the left or right response location or the polarity correspondence between the polarity codes of the number magnitudes and response locations. Gevers et al.'s (2005) account is basically based on the assumption that the SNARC effect is due to the left-to-right ordered mental number line. However, the polarity correspondence principle assumes that the SNARC effect is due to the polarity codes for number's magnitude information, not due to the left-to-right ordered mental number line.

Also, as in Gevers et al.'s (2005) and Mapelli et al.'s (2003) studies, we examined the temporal dynamics of the SNARC and spatial SRC effects by using the bin analysis (De Jong, Liang, & Lauber, 1994; Proctor, Miles, Baroni, 2011). In Experiment 1, participants performed the magnitude judgment task with laterally presented target numerals. Thus, the spatial correspondence between task-irrelevant left-right stimulus location and left-right response causes the Simon effect. If the SNARC effect is due to the numbers being coded along a horizontal dimension, the SNARC effect would interact with the Simon effect. In Experiment 2, in which a stimulus number was presented either above or below the central fixation, the compatibility between up-down stimulus location and left-right response would cause the orthogonal Simon effect. If the SNARC effect is due to the correspondence between the polarity code of the number magnitude and the response location, the interaction of SNARC and orthogonal Simon effects would be expected.

Experiment 1

Experiment 1 tested whether SNARC compatibility interacts with Simon compatibility by using the additive factor method (AFM, Sternberg, 1969). Several researchers have used paradigms in which the number location was manipulated horizontally to uncover possible interaction of the SNARC and Simon effects, but results have not been consistent. For example, in Mapelli et al.'s (2003) Experiment 1, the size of the SNARC effect was not modulated by Simon compatibility. Also, the SNARC effect increased with increasing RT, whereas the Simon effect decreased as RT increased. However, in Keus and Schwarz (2005), the SNARC effect was obtained on the Simon-incompatible trials, but not on the Simon-compatible trials in their Experiment 2, in which participants performed a parity task. Moreover, Gevers et al. (2005) found that a significant Simon effect on the SNARC-compatible trials in fast responses was reversed in slow responses. However, this reversed Simon effect in the slow responses was not found on the SNARC-incompatible trials.

Although all Mapelli et al. (2003), Keus and Schwarz (2005), and Gevers et al. (2005) had participants respond to an Arabic digit presented to the left or right of fixation in their experiments, different results were obtained regarding the interaction of the SNARC compatibility and Simon compatibility. Thus, we carried out a reexamination of whether the SNARC effect is modulated by the Simon compatibility. In Experiment 1, as in the previous experiments, participants were to make a bimanual keypress response to the magnitude of a single digit Arabic numeral presented to either the left or right to central fixation. The interaction of the number location and the response location would be evident, resulting in the Simon effect, as well as the interaction of its magnitude and the response location, resulting in the SNARC effect. If the SNARC effect is caused by the correspondence of the left or right location of the number on the number line with the left or right response location, the SNARC effect should be modulated by the Simon compatibility. That is, the SNARC effect should disappear, or at least, decrease for the Simon-incompatible trials, whereas it should be evident for the Simon-compatible trials, especially when the responses are fast. However, if the SNARC effect is caused by the polarity correspondence, the SNARC effect should be constant regardless of the Simon compatibility because the influence of the polarity correspondence is not strong enough in the Simon task, relative to the spatial correspondence

(Proctor & Cho, 2006).

Method

Participants Twenty four undergraduates (male: 11, female: 13) at Korea University participated in partial fulfillment of a course requirement. All were right-handed and had normal or corrected-to-normal visual acuity as determined by self reporting.

Apparatus and stimuli Stimuli were presented against a dark gray background on a CRT monitor (17 in.) of a personal computer viewed at a distance of approximately 60 cm. The stimuli were controlled by E-Prime software (Version 1.2, Psychology Software Tools, Pittsburgh, PA). Responses were made by pressing one of the leftmost and rightmost key among five keys on a Micro Experimental Laboratory 2.0 response box with the left or right index finger.

The imperative stimulus for the magnitude judgment task was a white Arabic digit (0.8 cm x 0.8 cm, 0.7° x 0.7°) from 1 to 9 without 5, which was randomly presented 2.2cm(2.1°) to the left or right of a white fixation column. The fixation column consisted of three vertically

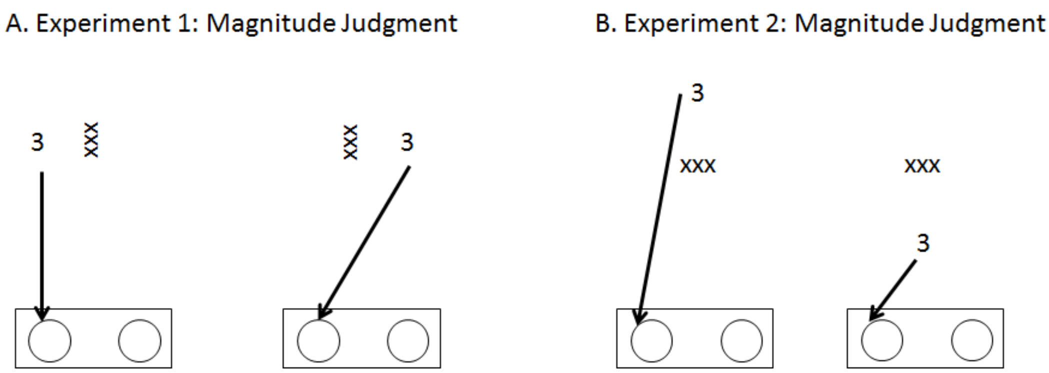

Figure 1. Schematic depiction of stimulus displays and stimulus-response compatibilities. A. In Experiment 1, an Arabic numeral was presented to the left or right of fixation column. Participants compared magnitude of an Arabic numeral with 5 and press right or left response key according to the instruction. The position of an Arabic numeral was task irrelevant. Example shown here is a small-left/large-right (i.e. SNARC compatible) condition. The example on the left represents the Simon compatible condition and on the right represents the Simon incompatible condition. B. In Experiment 2, a new group of participants performed a magnitude judgment task, in which an Arabic numeral was presented above or below the fixation row. Example shown here, again, small-left/large-right condition. An example on the left represents the orthogonal Simon incompatible condition and on the left represents the orthogonal Simon compatible condition.

arrayed Xs (0.5 cm x 0.5 cm, 0.4° x 0.4° for each X) on a dark background (see Figure 1).

Procedure The experiment took place in a sound-proofed room with dim light. Participants were instructed to align their body midline with the center of the screen and put each index finger on the left and right key of the response box. Each participant received 16 practice trials and 160 main trials. Half of the participants were told to press the left key to the numbers smaller than 5 and the right key to the numbers larger than 5 and to ignore the location of the Arabic digit and the other half performed the task with the alternative mapping to prevent the participants from confusion about the task-rule.

At the beginning of each trial, the fixation column was presented at the center of the screen. Participants were instructed to stare at it. After 500 ms, the imperative stimulus was presented to the left or right of the fixation column. The fixation column and the digit remained on the display until a response was made. A 500-Hz tone was given for 500 ms as feedback through the exterior speaker when an incorrect response was made. The fixation column for the next trial appeared 1,000 ms after the response or the error feedback.

Results

RTs shorter than 100 ms and longer than 1,000 ms were excluded from data analysis as outliers (10 trials out of 3,840 trials, < 1.0%). To see the temporal dynamics of the Simon and SNARC effects, RTs for correct trials for each participant were rank-ordered from the fastest to the slowest separately for Simon compatibility. Then, each RT distribution was divided into five 20% bins. The mean correct RT and percent error (PE) were calculated for each participant as a function of SNARC compatibility, Simon compatibility and RT bin. Analyses of variance (ANOVAs) were conducted on the mean RT and PE data, with Simon compatibility

Table 1. Mean Reaction Time (in milliseconds) and Percentage of Error in Experiment 1 as a Function of SRC and SNARC Compatibility.

SRC	SNARC compatibility				SNARC effect	
	Small-left/Large-right		Small-right/Large-left			
	RT	PE	RT	PE	RT	PE
Compatible	429	2.19	465	2.62	36	0.43
Incompatible	437	1.77	462	1.98	25	0.21

(Simon-compatible or Simon-incompatible), RT bin as within-subject variables and SNARC compatibility (SNARC-compatible or SNARC-incompatible) as a between-subject variable. Mean RT and PE data are shown in Table 1.

RT No significant main effect of SNARC compatibility, F (1,22) = 2.51, p = .1274, MSE = 22,148, or Simon compatibility, F < 1, was obtained. Most importantly, SNARC compatibility and Simon compatibility did not interact, F (1, 22) = 2.06, p = .1657, MSE = 935. A significant main effect of RT bin, F (4, 88) = 410, p < .001, MSE = 836, interacted with both SNARC compatibility, F (4, 88) = 3.65, p = .009, MSE = 836, and Simon compatibility, F (4, 88) = 8.48, p < .001, MSE = 220. For the SNARC effect, simple main effect analysis showed a non-significant 14 ms SNARC effect at the fastest bin, F (1, 88) = 3.15, p = .079, increasing to a significant 21 ms, F (1, 88) = 6.50, p = .013, 24 ms, F (1, 88) = 8.90, p = .004, 35 ms, F (1, 88) = 18.19, p < .001, and 55 ms F (1, 88) = 44.32, p <.001, as RT increased (2nd, 3rd, 4th and 5th bins, respectively, see Figure 2). On the other hand, for the Simon effect, a significant 18 ms Simon effect at the fastest bin, F (1, 88) = 17.19, p < .001, decreased to a significant 11 ms, F (1, 88) = 7.29, p = .0083 at the second fastest bin and non-significant 1 ms, F <1, at the third bin. A marginally significant -9 ms Simon effect at the fourth bin, F (1, 88) = 3.68, p = .058, reversed to a −12 ms

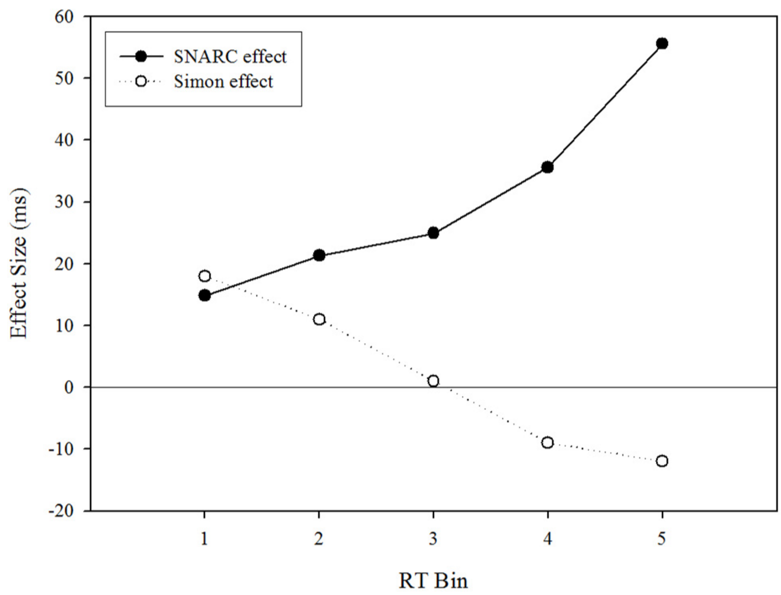

Figure 2. The Simon and SNARC effect as a function of RT bin in Experiment 1.

effect at the latest bin, F (1, 88) = 3.15, p = .079, was obtained. Finally, the three-way interaction of SNARC compatibility, Simon compatibility and RT bin was not significant, $F < 1$.

PE Overall PE was 2.14%. There was no significant main or interaction effect except the main effect of RT bin, F (4, 88) = 3.11, p = .019, MSE = 11.84. PE decreased as RT increased (3.25%, 2.84%, 1.69%, 1.69%, and 1.19%, respectively).

Discussion

The outcome of Experiment 1 did not provide evidence indicating that the SNARC and Simon effects have a common underlying mechanism. That is, as in Mapelli et al.'s (2003) Experiment 1 and Gevers et al.'s (2005) Experiment 2, the size of the SNARC effect was not modulated by the Simon compatibility. A 36-ms SNARC effect was obtained for the Simon-compatible trials, which did not significantly differ from the 25-ms SNARC effect for the Simon-incompatible trials. Moreover, the SNARC and Simon effects showed different temporal dynamics. The Simon effect decreased as RT increased and it was reversed at the slowest RT bin. The reversed Simon effect at the slowest RT bin is consistent with previous reports (Hommel, 1993; Mapelli et al., 2003; Gevers et al., 2005), indicating active suppression of the response induced by stimulus location rather than passive decay. The SNARC effect, on the other hand, increased with RT bin, as in Gevers et al.'s (2005) Experiment 2.

More important, no significant three-way interaction of Simon compatibility, SNARC compatibility and RT bin was obtained ($F < 1$), as in Mapelli et al.'s (2003) Experiment 1. The Simon effect decreased with RT bin regardless of SNARC compatibility, (22, 15, 5, −2, and −2 ms for SNARC-compatible trials, and 13, 7, −3, −14, and −20 ms for SNARC-incompatible trials, respectively). That is, the temporal dynamic of the SNARC effect was not modulated by Simon compatibility. It is important to note that Gevers et al. (2005) found the three-way interaction in their Experiment 2, even though its p value did not exceed the .05 level ($p < .08$). They found that the Simon effect was larger at faster bins for SNARC-compatible trials than SNARC-incompatible trials, and concluded that "the SNARC and Simon effect had mutually enhancing effects due to the high degree of temporal overlap" (p. 668). That is, because the SNARC effect is caused by the spatial code associated with the magnitude information, which is related to the spatial code associated with the location information, the SNARC compatibility had an impact on the ability to suppress the irrelevant spatial code associated with the location information. However, if this is the case, the reversed Simon effect at the slower bins should have been more evident for the SNARC-incompatible trials than for the SNARC-compatible trials because suppression of the response which is activated by task-irrelevant information might be enhanced more for the SNARC-incompatible trials than the SNARC-compatible trials.

Experiment 2

The results of Experiment 1 did not show that the SNARC effect is a phenomenon that results from the spatial correspondence between the left or right location of the number on the mental number line and the explicit response location. The purpose of Experiment 2 was to investigate whether the SNARC effect is due to the polarity correspondence, as Proctor and Cho (2006) suggested. In this experiment, participants performed the magnitude-judgment task as in Experiment 1, but a single-digit Arabic numeral appeared above or below fixation. So, the task-irrelevant stimulus location and the response location could yield the orthogonal Simon effect.

If the SNARC effect is due to the correspondence between the stimulus and response polarity codes, the SNARC effect should be modulated as a function of the orthogonal SRC pairings. According to the polarity correspondence principle (Proctor & Cho, 2006, also see Cho & Proctor, 2003), stimuli and responses are coded in terms of multiple frames of reference, and the sum of these multiple codes contributes to the polarity correspondence. Thus, when a stimulus numeral is presented above or below fixation, it is coded in terms of both its magnitude and location. For example, polarity correspondence between a larger number (+) and the right response (+) would be evident when it is presented above fixation (+). However, polarity correspondence would be ambiguous when it is presented below fixation (−) because of a negative polarity code of the stimulus location. The opposite pattern is expected for the small numbers. That is, polarity correspondence between a small number (−) and the left response (−) is more evident when it is presented below fixation (−) than when it is presented above fixation (+). As a result, the SNARC effect is larger when the large (small) numbers are presented above (below) than below (above) fixation.

In addition, if the SNARC effect is due to polarity correspondence, the temporal dynamics of the effect should be modulated as a function of orthogonal Simon compatibility. As we mentioned in Introduction, both the orthogonal SRC and SNARC effects increase with RT (Adam et al., 1998; Cho & Proctor, 2001;

Gevers et al. 2005; Mapelli et al. 2003). This increasing function of the SNARC effect is possibly a result of the slow formation of polarity codes for the magnitude of the numerals. If so, the SNARC effect should increase with RT bin for the orthogonal Simon-compatible trials, but it should be constant across RT bins for the orthogonal Simon-incompatible trials because the effect of the polarity codes associated with the number location would be cancelled out by the effect of the polarity codes associated with the number magnitude. Specifically, for the up-right/down-left trials, the effect of the polarity correspondence would be more evident at slow bins than fast bins. In contrast, for the up-left/down-right trials, the SNARC effect would be relatively constant across bins.

Method

Participants Twenty four undergraduates (male: 9, female: 15) at Korea University participated in partial fulfillment of a course requirement. All were right-handed and had normal or corrected-to-normal visual acuity as determined by self-reporting.

Apparatus, Stimuli and Procedure All experiment apparatus, stimuli and procedure were identical to those in Experiment 1 except for the locations of the Arabic numeral and the fixation marker. In Experiment 2, an Arabic numeral was randomly presented above or below the fixation row “XXX” (see Figure 1).

Results

As in Experiment 1, 0.1% of the trials (4 trials out of 3,840 trials) were removed using the same RT cutoff criteria. Mean correct RT and PE were calculated for each participant as a function of orthogonal Simon compatibility, SNARC compatibility, and RT bin (see Experiment 1). Analysis of variance (ANOVAs) was conducted on the mean RT and PE data, with orthogonal Simon compatibility (up-right/ down-left or up-left/down-right), RT bin (5) as within-subject variables and SNARC compatibility (SNARC-compatible or SNARC-incompatible) as a between-subject variable. Mean RT and PE data are shown in Table 2.

RT Both *the* main effect of SNARC compatibility, $F < 1$, and orthogonal Simon compatibility, F (1, 22) = 1.70, p = .206, MSE = 587, were not significant. Importantly, these two variables showed a significant interaction, F (1, 22) = 12.61, p = .002, MSE = 587. A significant 16-ms SNARC effect was obtained on the up-right/down-left trials, F (1, 22) = 13.22, p = .001, MSE = 587, but a

Table 2. Mean Reaction Time (in milliseconds) and Percentage of Error in Experiment 2 as a Function of orthogonal SRC mapping and SNARC Compatibility

Orthogonal SRC	SNARC compatibility					
	Small-left/Large-right		Small-right/Large-left		SNARC effect	
	RT	PE	RT	PE	RT	PE
URDL	435	1.26	451	2.19	16	0.93
ULDR	450	1.78	444	0.53	-6	-1.25

Note : URDL = Up-Right/Down-Left; ULDR = Up-Left/Down-Right

non-significant -6-ms SNARC effect was found on the up-left/down-right trials, F (1, 22) = 1.92, p = .179, MSE = 587. The main effect of RT bin was significant, F (4, 88) = 532.90, p < .001, MSE = 495. However, even though the SNARC effect tended to increase with RT bins (2, 3, 3, 6, and 11 ms, respectively), the interaction of SNARC compatibility and bin was not significant, F < 1. Also, although the orthogonal Simon effect tended to increase with RT bins (2, -1, 2, 5, and 12 ms, respectively), the interaction of orthogonal Simon compatibility with bin was not significant either (see Figure 3), F (4, 88) = 1.34, p = .261, MSE = 216.

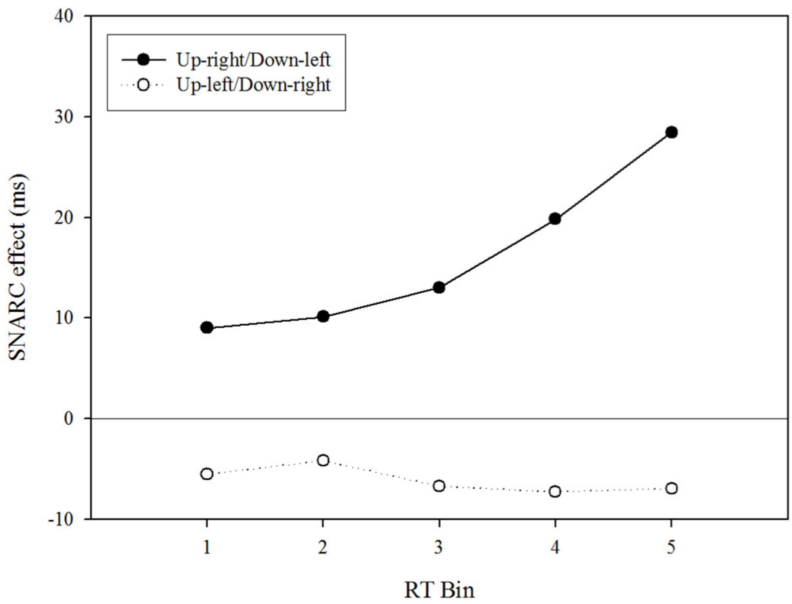

Figure 3. The magnitude of the SNARC effect as a function of the orthogonal Simon compatibility and RT bin in Experiment 2.

Finally, although the 3-way interaction of SNARC compatibility, orthogonal Simon compatibility, and RT bin was not statistically significant, F (4,88) = 1.13, p = .348, the SNARC effect tended to increase with RT bins for the up-right/down-left trials (9, 10, 13, 19, and 28 ms, respectively), but it tended to be constant for the up-left/down-right trials (－5, －4, －6, －7, and －6 ms, respectively; see Figure 3).

PE The overall PE was 1.43%. The main effects of SNARC compatibility, F < 1, and orthogonal Simon compatibility, F (1, 22) = 1.62, p = .216, MSE = 11.98, were not significant. Of most importance, like RT data, SNARC compatibility interacted with orthogonal Simon compatibility, F (1, 22) = 5.95, p = .023, MSE = 11.98. A non-significant 0.9 % SNARC effect obtained for the up-right/down-left trials, F (1, 22) = 2.16, p = .155, MSE = 11.98, was reversed to a － 1.2 % for the up-right/down-left trials, F (1, 22) = 3.91, p = .061, MSE = 11.98. No other main or interaction effect was significant except for the main effect of RT bin, F (2, 88) = 5.95, p = .005, MSE = 10.93. PE increased with RT bins (3.12%, 1.19%, 1.04%, 1.04%, 0.78%, respectively).

Discussion

The results of Experiment 2 provided evidence for the idea that the SNARC effect is due to the polarity correspondence, as Proctor and Cho (2006) suggested. Of most interest, SNARC compatibility interacted with orthogonal Simon compatibility: A 16-ms SNARC effect obtained on the up-right/down-left trials reversed to a nonsignificant - 6-ms on the up-left/down-right trials. This result is consistent with the results obtained in Bae et al.'s (2009) Experiment 3, which showed a larger SNARC effect when participants performed the orthogonal SRC task with up-right/down-left mapping (30 ms) than with up-left/down-right mapping (18 ms).

Although they were not significant, both the SNARC and the orthogonal Simon effects tended to increase with RT bins (2, 3, 3, 6, and 15 ms for the orthogonal Simon effect, and 2, －1, 2, 5, and 12 ms for the SNARC effect). These patterns were also obtained when the location of an imperative stimulus was task-relevant in the orthogonal SRC task (Adam, Boon, Paas & Umiltà, 1998; Cho & Proctor, 2001). For example, in Cho and Proctor's Experiment 1, the up-right/down-left advantage increased with RT when the advantage was evident. The authors attributed this result to the slow formation of the polarity codes. Likewise, the increasing pattern of the SNARC effect with RT bin in the present experiment indicates that the polarity code associated with number magnitude was also formed slowly.

One more interesting result is that this increasing pattern of the SNARC effect changed numerically as a function of the orthogonal Simon compatibility (see Figure 3). The SNARC effect increased with RT for the up-right/ down-left trials, but it was constant for the up-left/down-right trials. These patterns are obtained because the polarity codes associated with the number location and its magnitude are assumed to be formed slowly. Thus, at fast RT bins, because the polarity codes associated with both number location and magnitude were not formed, the SNARC effect was not evident for both up-right/down-left trials and up-left/ down-right trials. At slow RT bins, however, because the polarity codes associated with the magnitude and location of the number were formed, the size of the SNARC effect increased as RT increased for the up-right/ down-left trials but not for the up-left/ down-right trials.

General Discussion

Primary outcomes

The purpose of the present study was to test whether the SNARC effect is due to the spatial correspondence between the location of an Arabic numeral on a mental horizontal number line and response location or that of the correspondence between the stimulus and response polarity codes. Participants made a left-right bimanual response to the magnitude of a single-digit Arabic numeral presented at the left or right side of the fixation column (Experiment 1) or above or below the fixation row (Experiment 2). In Experiment 1, the size of the SNARC effect remained constant regardless of the Simon compatibilities. Also, the SNARC and Simon effects showed different temporal dynamics, with the Simon effect decreasing but the SNARC effect increasing as RT increased. In addition, the 3-way interaction of SNARC compatibility, Simon compatibility, and RT bin was not at all significant. These results suggest that the SNARC effect obtained in the magnitude-judgment task was not due to the left or right number location on the mental number line representation.

On the other hand, the findings of Experiment 2 indicate that the SNARC effect shares a common underlying mechanism with the orthogonal Simon effect. That is, in Experiment 2, the SNARC effect was modulated by the orthogonal Simon compatibility. A 16-ms SNARC effect was obtained on the up-right/ down-left trials, while a nonsignificant 6-ms reversed SNARC effect was seen on the up-left/down-right trials. Even though the 3-way interaction of SNARC compatibility, the orthogonal Simon compatibility, and RT bin was not significant, the SNARC tended to increase with RT bins on the up-right/down-left trials but was constant across bins on the up-left/down-right trials. On the up-right/ down-left trials, because the polarity codes associated with the number magnitude and its location are formed at a later point in time, the SNARC effect increased with RT bins. However, on the up-left/down-right trials, because the polarity codes associated with the number magnitude were nullified by the polarity codes associated with its location, no SNARC effect occurred across RT bins.

It is important to note that the SNARC and orthogonal Simon effects were more evident when responses were slow than fast. Recently, Wiegand and Wascher (2007) suggested that there are two types of the Simon effects arising from different underlying mechanisms. One is the visuo-motor Simon effect which occurs between stimulus location and anatomical status of the effector. The other is the cognitive Simon effect which is due to the code interference process. The authors pointed out that the magnitude of the visuo-motor Simon effect decreases as RT increases, while that of the cognitive Simon effect increases. Thus, the spatial correspondence effect, which decreased as RT increased, obtained in Experiment 1 of the present study is a visuo-motor Simon effect. However, the orthogonal Simon and SNARC effects, which increased as RT increased, were not due to the correspondence between stimulus location and anatomical status of effector but to the code interference process, which is possibly the polarity code correspondence.

The SNARC effect as a result of the polarity correspondence

Several studies have shown that the SNARC effect originates from spatial correspondence between the left-to-right location on the mental number line representation and response location (Gevers et al., 2003, Notebaert et al., 2006). However, it has been also found that the SNARC effect is not restricted to the left-to-right ordered spatial nature of the number representation. For example, when Ito and Hatta (2004) had participants perform the parity judgment task with a vertically arrayed response set, performance was better with small-bottom/large-top pairings than with small-top/large-bottom pairings. In addition, Gevers, Lammertyn, Notebaert, Verguts, and Fias (2006) reported that a regular SNARC effect occurs when participants responded with a right diagonal response set (1 and 9 keys of the number keypad on a desk-top computer keyboard), but it disappeared when they responded with a left diagonal response set (3 and 7 keys of the number keypad). That is, the SNARC effect can be modulated by the orientation of the response set.

These results imply that the SNARC effect is due to the polarity correspondence between the number magnitudes and response alternatives. The "small-bottom/large-top" advantage obtained by Ito and Hatta (2004) was a result of the correspondence between the polarity codes for large numbers (+) and the up response location (+) and between the polarity codes for small numbers (−) and the down response location (−). Also, the lack of the SNARC effect obtained when the response set was the left diagonal in Gevers et al.'s (2006) experiment is due to the lack of evident polarity correspondence. That is, for example, the polarity code for the up-left response key was positive (+) in terms of the vertical dimension (up) but negative in terms of the horizontal dimension (left), resulting in no evident polarity correspondence with the number magnitude.

Moreover, a reversed SNARC effect was obtained when participants performed a magnitude-judgment task with unimanual movement of their index finger to one of two response keys located to the left of the home key, whereas a regular SNARC effect when the movement direction was the right of the home key (Santens & Gevers, 2008). Also, the SNARC effect was larger after practicing the orthogonal SRC task with up-right/down-left mapping than up-left/down-right mapping, whereas the SNARC effect was not modulated by practice mapping for the parallel SRC task (Bae et al., 2009). These results directly indicate that the spatial horizontal number line is not necessary to obtain the SNARC effect but the polarity correspondence is sufficient to yield the effect.

Conclusion

Since Dehaene et al. (1993) first demonstrated the SNARC effect, several studies have typically interpreted it as a spatial correspondence phenomenon similar to the Simon effect. However, the present study failed to find evidence supporting a view that the SNARC effect arises from the mechanism causing the Simon effect. Instead, the results showed the SNARC effect share a common underlying mechanism with the orthogonal Simon effect: Both the SNARC effect and the RT distribution of it varied as a function of the orthogonal Simon compatibility. As Proctor and Cho (2006) suggested, these results are consistent with the idea that the SNARC effect is a consequence of the correspondence between stimulus and response categorical code polarities, rather than correspondence between the locations of numbers on the left-to-right ordered implicit mental number line and those of responses.

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공간 부합성과 SNARC 효과의 상호작용

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숫자 자극에 좌우 반응을 할 때, 작은 숫자를 왼쪽으로, 큰 숫자를 오른쪽 반응으로 하는 것이 그 반대로 하는 것보다 수행이 우수하다. 이러한 반응 부호화의 공간 숫자 연합(Spatial Numerical Association of Response Code, SNARC) 효과를 설명하기 위해 수평 숫자선 이론(horizontal number line account)은 숫자들이 크기에 따라 좌우로 심적 부호화되어 있기 때문에 SNARC 효과가 나타난다고 하였으며, 양극화 부합성 원리(polarity correspondence principle)는 숫자의 크기 정보가 양, 또는 음극으로 부호화되기 때문에 그 효과가 나타난다고 한다. 본 연구는 SNARC 효과가 심적 숫자 선에서 숫자의 좌우 위치와 반응의 위치 사이의 공간 합치성 때문에 나타나는지 아니면 숫자의 크기와 반응의 위치에 대한 양극부호 사이의 합치성 때문에 나타나는 것인지 알아보자 하였다. 실험 1에서 실험 참여자가 고정점의 오른쪽 또는 왼쪽에 제시된 아라비아 숫자의 크기에 대해 반응할 때, 자극과 반응의 위치 사이의 Simon 효과와 관계없이 SNARC 효과의 크기는 일정하였다. 이와 반대로 고정점의 위, 또는 아래에 제시된 아라비아 숫자의 크기에 대해 반응할 때에는 위-왼쪽/아래-오른쪽으로 반응하는 경우가 위-오른쪽/아래-왼쪽으로 반응하는 경우보다 SNARC 효과의 크기가 더 작았다. 이러한 결과는 SNARC 효과가 양극성 부합 때문에 나타난다는 의견을 지지한다.

주요어 : SNARC 효과, Simon 효과, 직교 Simon 효과, 자극-반응 부합성 효과, 양극성 부합