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Referential Coding Contributes to the Horizontal SMARC Effect

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The present study tested whether coding of tone pitch relative to a referent contributes to the correspondence effect between the pitch height of an auditory stimulus and the location of a lateralized response. When left–right responses are mapped to high or low pitch tones, performance is better with the high–right/low–left mapping than with the opposite mapping, a phenomenon called the horizontal SMARC effect. However, when pitch height is task irrelevant, the horizontal SMARC effect occurs only for musicians. In Experiment 1, nonmusicians performed a pitch discrimination task, and the SMARC effect was evident regardless of whether a referent tone was presented. However, in Experiment 2, for a timbre-judgment task, nonmusicians showed a SMARC effect only when a referent tone was presented, whereas musicians showed a SMARC effect that did not interact with presence/absence of the referent. Dependence of the SMARC effect for nonmusicians on a reference tone was replicated in Experiment 3, in which judgments of the color of a visual stimulus were made in the presence of a concurrent high- or low-pitched pure tone. These results suggest that referential coding of pitch height is a key determinant for the horizontal SMARC effect when pitch height is irrelevant to the task.

Keywords: auditory compatibility, polarity coding, Simon effect, SMARC effect, SPARC effect

Spatial correspondence between stimulus and response alternatives has a strong influence on the response-selection process (e.g., Proctor & Vu, 2006). For example, left–right responses are faster and more accurate when the stimulus and response correspond spatially than when they do not, regardless of whether the stimulus location is task relevant or irrelevant (see Hommel & Prinz, 1997). This stimulus–response compatibility (SRC) effect is also obtained with various other types of stimulus and response sets. For instance, when people make an up or down response to a high or low pitched tone, performance is usually better for the mapping of the high tone to the up response and the low tone to the down response than for the opposite mapping. This phenomenon is called the spatial musical association of response code (SMARC) effect (Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006) or, alternatively, the spatial pitch association of response code (SPARC) effect (Lidji, Kolinsky, Lochy, & Morais, 2007). This SMARC effect also occurs when responses are made to the timbre of the tone (Lidji et al., 2007; Rusconi et al., 2006) or the color of a visual stimulus (Nishimura & Yokosawa, 2009), rather than to the tone's pitch, much like the spatial SRC effect obtained when stimulus location is task irrelevant (called the Simon effect; e.g., Simon & Rudell, 1967).

This vertical SMARC effect is thought to be due to associations of pitch height with space, much like the more widely studied spatial–numerical association of response codes (SNARC) effect is attributed to associations of number magnitude (small or large) with space (left or right; Lidji et al., 2007; Rusconi et al., 2006). That is, pitch height is spatially represented as a vertically ordered line with low pitch tones located on the lower part and high pitch tones on the upper part of the mental pitch line. Rusconi et al. (2006) proposed that the "human cognitive system maps pitch onto a mental representation of space" (p. 126). Because high pitched tones are located on the upper part and low pitched tones on the lower part of the vertically arrayed mental representation of pitch height, spatial correspondence between the musical pitch and upper–lower responses occurs. Lidji et al. (2007) suggested that the compatibility effect between pitch height and vertical response is obtained because of an intrinsic characteristic of the tone pitch.

The SMARC effect is also obtained with a horizontal response set. When Lidji et al. (2007) had participants perform a pitch comparison task with left–right responses in their Experiment 2, performance was better with the mapping of "high–right/low–left" than with that of "high–left/low–right" for both musicians and nonmusicians. Rusconi et al. (2006) also found a 16.5-ms "high–right/low–left" advantage in their Experiment 1, although it was not statistically significant. They suggested that the SMARC effect obtained with the lateralized response set is consistent with the view that the mental representation of pitch is spatially multidimensional (Mudd, 1963), having a horizontal representation as well as a vertical one. In addition, Rusconi et al. and Nishimura

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and Yokosawa (2009) speculated that the SMARC effect with the lateralized response set could instead be a spatial orthogonal SRC effect. That is, when participants make left–right responses to up–down stimuli, an overall up–right/down–left mapping advantage is usually obtained (Cho & Proctor, 2003; Weeks & Proctor, 1990). By this account, because a high pitch tone is spatially coded as "up" and a low pitch tone as "down," performance is better with the "high–right/low–left" mapping than with the alternative mapping.

However, when participants were to make a left or right response to a dimension other than the pitch height of the tone, the SMARC effect was evident only for musically trained participants (Lidji et al., 2007; Rusconi et al., 2006). In Lidji et al.'s Experiment 1, in which a timbre-judgment task with lateralized responses was performed, the nonmusicians showed no "high–right/low–left" advantage (2 ms), whereas the musicians showed a significant 18-ms advantage. That is, when the pitch of the tone was task irrelevant, the SMARC effect was evident only for persons who had received extensive musical training. The authors suggested that the lack of a "Simon"-type horizontal SMARC effect is due to pitch not automatically evoking horizontal associations for nonmusicians when pitch height is irrelevant to the task.

According to Lidji et al. (2007), because musicians are (1) more sensitive to small pitch changes and (2) more likely to process musical stimuli automatically than are nonmusicians, the horizontal spatial representations associated with pitch are unintentionally activated for musicians but not for nonmusicians when the pitch is task irrelevant. Musicians have the ability to associate the pitch with lateralized responses even when it is irrelevant to the task, whereas nonmusicians associate pitch height with the lateralized responses only when they are required explicitly to process pitch (Lidji et al., 2007). Lidji et al. suggested that the SMARC effect with lateralized responses is probably due to musicians' ability to use the keyboard of a piano, with which they are familiar, as a referent for coding pitch low-to-high pitch from left-to-right along the horizontal dimension.

Recently, Nishimura and Yokosawa (2009) obtained a significant 8-ms SMARC effect when a group of participants not selected with respect to a musical training criterion were to indicate whether a visual target stimulus, accompanied by an accessory high or low pitch tone to the left or right ear, was red or green. However, those authors suggested that the musical training of the participants during elementary and junior high school may have been sufficient to form the spatial–pitch association. Using similar logic, the lack of the SMARC effect with the horizontal response set for nonmusicians in Lidji et al.'s (2007) and Rusconi et al.'s (2006) experiments implies that the relative code of pitch height was not formed in them. It should be noted that, in both Lidji et al.'s and Rusconi et al.'s studies, no referent tone was presented when pitch height was task irrelevant, whereas one was presented when pitch height was task relevant, a factor that may be crucial to the obtained results.

Actually, to explain the spatial SRC effect, many coding accounts have been proposed based on the assumption that stimulus and response locations are spatially coded. According to these coding accounts, the SRC effect is due to conflict between the spatial stimulus and response codes in response selection when the stimulus code does not correspond to the response code (Hommel, 1997; Umiltà & Nicoletti, 1990). Unlike coordinate spatial representations (which are a type of spatial information that specifies precise distance, orientation, or size in the coordinates), codes that specify categorical spatial information are relational (Kosslyn, 1994). That is, categorical spatial codes denote a relation between a target object and referent point(s), which can be other object(s) or location(s). The spatial correspondence effect in two-choice tasks has been found to be based in the referential coding of the stimulus and response locations. In Hommel's (1993) Experiment 3, when a target and a referent object were presented within a precue (a rectangular frame presented at the left or right side of the screen), a Simon effect between the target location relative to the referent object and the response location was evident regardless of the side to which the frame was presented. Because the left or right spatial code for the target stimulus was formed in terms of a referent object, performance was better when the stimulus and response spatially corresponded than when they did not.

A characteristic of categorical codes is that they are asymmetric (Kosslyn, 1994), with one alternative being the polar referent (+ polarity) and the other being coded relative to it (– polarity). This coding asymmetry has been implicated as the basis for orthogonal SRC effects, specifically, the up–right/down–left mapping advantage that is obtained when vertically oriented visual stimuli are mapped to horizontally arrayed responses (Cho & Proctor, 2003; Proctor & Cho, 2006). A variety of evidence indicates that up and right are coded as + polarity and down and left as – polarity for the respective dimensions (e.g., Clark & Chase, 1972; Olson & Laxar, 1973; Seymour, 1974). Thus, the up–right/down–left mapping maintains correspondence between code polarities, whereas the up–left/down–right mapping does not. Rusconi et al. (2006); Lidji et al. (2007), and Nishimura and Yokosawa (2009) all suggested that the SMARC effect obtained with left–right responses may be a type of orthogonal SRC effect (tones coded on vertical dimension mapped to responses on the horizontal dimension), with the latter authors emphasizing that the SMARC effect could be explained by polarity correspondence.

Evidence implies that the up–right/down–left mapping advantage, indicative of polarity correspondence, occurs only when the stimulus and response alternatives are coded categorically. For experiments in which a precue was used to illustrate the mapping of the vertical stimulus locations to their assigned horizontal responses for each individual trial, an up–right/down–left advantage was obtained when the precue was verbal description but not when it was a graphic depiction (Adam, Boon, Paas, & Uliltà, 1998; Cho & Proctor, 2001; Kleinsorge, 1999). The apparent reason for this difference in results is that the verbal precues induced categorical coding, which has the property of code polarity, whereas the graphical precues induced coordinate coding, which does not (Cho & Proctor, 2003; Kleinsorge, 1999).

If the SMARC effect is based on categorical codes for pitch height, no SMARC effect would be obtained under conditions in which such categorical codes of the target tone pitch are not formed. Categorical coding of pitch is required for tasks that involve pitch identification, and so the SMARC effect in a pitch-identification task should be evident even for nonmusicians when a referent tone is not available. However, it is unlikely that nonmusicians code pitch height automatically without a referent tone when lateralized responses are made to a feature other than the pitch of the target tone. Thus, in Lidji et al.'s (2007) and Rusconi et al.'s (2006) studies, no categorical codes of pitch height may have been formed, resulting in an absence of SMARC effect. Because of their extensive training, musicians likely form categorical codes for pitch height automatically, even without a referent tone, resulting in a significant SMARC effect.

To test the hypothesis that a referent tone is crucial for nonmusicians to code pitch height automatically, we had nonmusicians perform a pitch-relevant task (Experiment 1), a timbre-judgment task (Experiment 2), and a color-discrimination task (Experiment 3), with or without a referent tone. Musicians were also tested in Experiment 2 to confirm that, for them, categorical coding of pitch height occurs automatically without need for a referent. In Experiment 1, participants were to discriminate whether the pitch of a pure tone was high or low. Half of the participants performed the task with a referent tone presented before onset of the target tone and the other half performed without it. Because pitch height must be coded explicitly since it is relevant to the task, the SMARC effect should occur regardless of whether the referent tone is provided.

In Experiment 2, a timbre-judgment task was adopted for which the pitch height was irrelevant to the task. If a referent is necessary for nonmusicians to code pitch height when it is irrelevant to the task, then they should show a SMARC effect when the referent tone is present but not when it is absent. In contrast, because musicians tend to code pitch height automatically, they should show a SMARC effect both in the presence and absence of the referent tone. Although pitch height was task irrelevant in Experiment 2, the auditory stimulus itself had to be processed successfully to perform the task. To make the tone completely irrelevant, Experiment 3 adopted the color-judgment task in which an auditory accessory pure tone was presented concurrently with a centrally presented visual target whose color had to be identified. The SMARC effect was anticipated to occur when nonmusicians performed the task with the referent but not without the referent. Because the main purpose of the study was to investigate the influence of the referent tone on the SMARC effect, two tones that were distinctly higher and lower pitch than the referent were used as imperative stimuli in all experiments. Note that the referent provides a basis for coding pitch height (i.e., a vertical dimension) and not for coding pitch along the horizontal dimension. Effects of the referent would therefore imply that the SMARC effect, at least for nonmusicians, is a form of orthogonal SRC effect.

Experiment 1: Pitch-Judgment Task

It has been reported that for nonmusicians, the SMARC effect with a horizontal response set occurs only when the pitch height is relevant to the task (Lidji et al., 2007). For example, in Lidji et al.'s Experiment 2, in which nonmusicians were told to decide whether a tone played by piano or violin was higher in pitch than a referent tone presented in the first three trials of the experiment only, they found a significant SMARC effect of 33 ms. According to Lidji et al., the pitch height evokes associated horizontal responses for nonmusicians if it is relevant to the task. To determine whether a referent tone contributes to the SMARC effect for nonmusicians when the pitch is relevant, in Experiment 1, half of the participants performed the pitch-judgment task with the referent tone given in each trial; the other half performed the task without the referent. Unlike Lidji et al.'s (2007) Experiment 2, a high or low pitch pure tone was used in the present experiment. Because pitch height must be coded when required by the task, the SMARC effect should be evident in this experiment regardless of whether the referent tone is present or absent.

Method

Participants. Thirty-two undergraduates (male: 19, female: 13) at Korea University participated in partial fulfillment of a course requirement. Seven had no prior musical experience; the other 25 had an average of 3.7 years of musical training and had stopped since 8.9 years of age on average. All were right-handed and had normal hearing as determined by self-report. Participants were randomly assigned to two groups: referent tone and no referent.

Apparatus and stimuli. Stimuli were controlled by E-Prime software (Version 1.2, Psychology Software Tools, Pittsburgh, PA). Responses were made by pressing the leftmost or rightmost key among five keys on a Micro Experimental Laboratory 2.0 response box with the left and right index fingers.

A white cross (0.5 cm × 0.5 cm, 0.4° × 0.4°) was presented against a dark gray background on a CRT monitor (17 in.) of a personal computer as a fixation viewed at a distance of approximately 60 cm. The imperative stimulus was a low-pitched pure tone (250 Hz) or high-pitched pure tone (1,000 Hz) which was given to the participants bilaterally through a PC convertible headphone. An intermediate-pitched pure tone (500 Hz) was used as the referent.

Procedure. The experiment took place in a soundproof booth 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 keys of the response box, which was lined up with the center of the screen. They were told to press the left or right key to the low or high pitch of each auditory stimulus as quickly as possible while maintaining high accuracy. The experiment consisted of two sessions of eight warm-up and 80 test trials each. Participants performed the pitch-judgment task with one mapping of high and low pitches to left and right responses in the first session and the other mapping in the second session, with order counterbalanced across participants. Preliminary analyses of variance (ANOVAs) on reaction time (RT) and percent error (PE), like those reported in the Results section but including the factor of order (high–right/low–left first or high–left/low–right first) showed only an Order × SMARC Mapping interaction for RT, $F(1, 28) = 4.52$, $p = .042$, mean standard error [MSE] = 1,032, $\eta_p^2 = 0.14$. This is simply a practice effect (larger SMARC effect when the compatible mapping was second [35 ms] than when it was first [22 ms]), which did not interact with referent condition, $F < 1.0$. Therefore, order was excluded from the reported ANOVAs.

At the beginning of each trial, the fixation cross was presented at the center of the screen for 500 ms. The referent tone was presented concurrently with the fixation cross for the referent group, but not for the group with no referent. The imperative auditory stimulus was presented for 500 ms, followed by a dark screen that remained until a response was made. The word "Incorrect" in white was displayed for 500 ms as feedback at the center of the screen when an incorrect response was made. The white fixation for the next trial appeared 500 ms after the correct response or the error feedback. A short rest period was given between the sessions.

Results

RTs shorter than 125 ms and longer than 1,250 ms were excluded as outliers (11 out of 5,120 trials, 0.21%). Mean correct RT and PE were calculated for each participant as a function of the SMARC mapping. ANOVAs were conducted on the mean RT and PE data (see Table 1), with SMARC mapping (high–right/low–left and high–left/low–right) as a within-subjects variable and referent condition (referent tone and no referent tone) as a between-subjects variable.

RT. The main effect of SMARC mapping was significant, $F(1, 30) = 11.49$, $p = .002$, $MSE = 1{,}120$, $\eta_p^2 = 0.28$: RT was shorter with the high–right/low–left mapping (mean [M] = 353 ms) than the high–left/low–right mapping ($M = 381$ ms). RT was longer with the referent tone ($M = 390$ ms) than without it ($M = 354$ ms), $F(1, 30) = 4.55$, $p = .041$, $MSE = 7{,}123$, $\eta_p^2 = 0.13$. Although the SMARC effect tended to be larger when the referent was present (34 ms) than when it was absent (23 ms), the interaction of SMARC mapping and referent was far from significant, $F < 1$ (see Figure 1).

PE. Overall PE was 0.72%. The main effect of referent was significant, $F(1, 30) = 6.89$, $p = .013$, $MSE = 1.87$, $\eta_p^2 = 0.19$. PE was higher when no referent tone was given (1.17%) than when the referent tone was given (0.27%). Neither the main effect of SMARC mapping nor the interaction of SMARC mapping and referent was significant, Fs < 1.

Discussion

As in Lidji et al.'s (2007) and Rusconi et al.'s (2006) experiments, performance of the pitch judgment task was better when participants performed the task with the high–right/low–left mapping than with the high–left/low–right mapping: A 28-ms SMARC effect was obtained. The magnitude of the SMARC effect with the referent (34 ms) did not differ significantly from that of the effect obtained without the referent (23 ms), indicating that pitch height was coded even when no referent was provided. The coding of the pitch height without a referent could be based on participants' memory because only two different target pitches were used and the participants had to process the pitch in order to perform the task. The results indicate that nonmusician participants are able to form the codes for pitch height when pitch is task relevant.

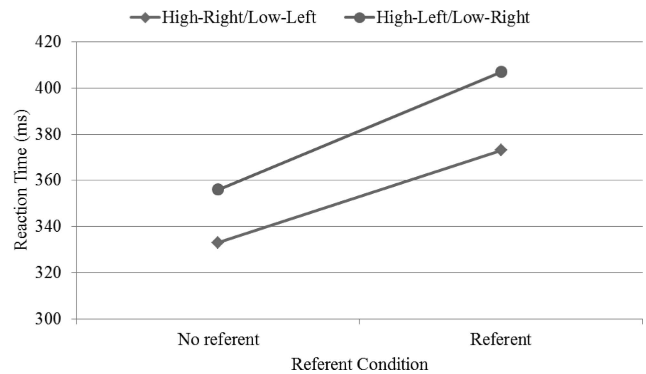

Figure 1. Mean reaction time as a function of SMARC mapping and referent in Experiment 1.

Lidji et al. (2007) suggested that the horizontal SMARC effect is likely driven by participants' knowledge of the usual order of singing or playing notes of the musical scale. However, that the SMARC effect was obtained with pure tones for nonmusicians suggests that it can occur without knowledge of music for tasks that require explicit tone categorization.

Experiment 2: Timbre-Judgment Task

The results of Experiment 1 showed that the SMARC effect occurred when pitch height was relevant to the task, regardless of whether a referent tone was present or not. This result is in agreement with Lidji et al.'s (2007) conclusion that nonmusicians "explicitly associate pitch with a left–right space" (p. 1193), although the result could occur as well through polarity correspondence of the low–high tones with the left–right responses. Experiment 2 examined the role of a referent when the pitch height was

Table 1
Mean (and Standard Deviation) Reaction Time (RT, ms) and Percentage of Error (PE) in Experiments 1, 2, and 3 as a Function of Referent Condition and SMARC Mapping

		SMARC mapping			
		High-right/low-left		High-left/low-right	
Group	Referent	RT	PE	RT	PE
Experiment 1: Pitch judgment	Without referent	333 (36.7)	1.01 (1.04)	356 (52.2)	1.33 (1.91)
	With referent	373 (61.2)	0.23 (0.50)	407 (93.1)	0.31 (0.72)
Experiment 2: Timbre judgment					
Nonmusicians	Without referent	569 (178.0)	4.38 (6.50)	562 (167.9)	7.00 (11.05)
	With referent	540 (140.1)	2.92 (5.95)	571 (164.0)	7.81 (11.87)
Musicians	Without referent	520 (128.9)	4.38 (7.84)	534 (123.5)	6.26 (10.90)
	With referent	522 (134.0)	4.01 (7.31)	545 (143.0)	7.30 (10.96)
Experiment 3: Color judgment	Without referent	361 (33.3)	0.52 (0.80)	360 (33.6)	1.45 (2.50)
	With referent	363 (46.3)	0.00 (0.0)	374 (47.2)	0.00 (0.0)

irrelevant to the task. In this experiment, the timbre-judgment task was adopted in which high and low pitch tones of a violin and a piano were presented and left–right responses were to be made to the timbre of the tone. Previous studies have reported that the SMARC effect with horizontal response set was evident only for musically trained participants when the pitch was task irrelevant (Lidji et al., 2007; Rusconi et al., 2006). For example, when nonmusicians judged whether a high or low pitch tone was produced by a wind or percussion instrument, Rusconi et al. failed to obtain a significant high–right/low–left advantage. Lidji et al. suggested that the reason why the SMARC effect with a horizontal response set was evident just for musicians is that only they have the ability to automatically activate a mental representation of pitch along the horizontal dimension when processing a sound's timbre.

However, in Rusconi et al.'s (2006) and Lidji et al.'s (2007) experiments, no referent tone was given when participants performed the timbre-judgment task. If referential coding is important for the SMARC effect, as it is for the spatial SRC task, the lack of the SMARC effect reported by Lidji et al. and Rusconi et al. for nonmusicians may have been due to the absence of a referent tone. To test this possibility, in Experiment 2, we had musicians and nonmusicians perform the timbre-judgment task, half with a referent pure tone and the other half without the referent tone. Without a referent tone, we expected to replicate the finding of a SMARC effect for musicians but not for nonmusicians. If, for the latter group, the SMARC effect is caused by correspondence between the polarities of the categorical codes for pitch height and those of the response spatial codes, the SMARC effect should be evident when the referent tone is provided. In contrast, if the SMARC effect is due to the spatial–musical association in the mental representation of the pitch height from using a familiar instrument, such as the piano keyboard, the SMARC effect should not be obtained for nonmusicians regardless of whether a referent is presented or not, because their ability to activate a horizontal mental representation of pitch would not change based on the presence of the nonmusical referent pure tone.

Method

Participants. Thirty-two new undergraduate nonmusicians (male: 10, female: 22) at Korea University participated in partial fulfillment of a course requirement. Five had no prior musical experience; the others averaged 3.5 years of musical training but had no training for the past 10.9 years. In addition, 32 undergraduate students who were majoring in music (male: 3, female: 29) participated for payment of approximately \$20 US. The musicians averaged 12.8 years of musical training. All of the nonmusicians and 26 of the musicians were right handed, and all participants had normal hearing as determined by self-report. Participants from each group were randomly assigned to two conditions: referent and no referent.

Apparatus, stimuli, and procedure. The apparatus, stimuli and procedure were identical to Experiment 1, except as noted. The imperative stimuli were two low-pitched (C3, 131 Hz) tones and two high-pitched (B5, 988Hz) tones, which were synthesized with piano and violin timbres. (These stimuli were provided by Pascale Lidji.) The referent tone was a pure tone (359 Hz) chosen to get the same tonal distance between low pitch (C3) and high pitch (B5) tones (17 steps including semitones). Each participant performed 12 warm-up and 120 test trials. Participants in the no referent group performed the timbre-judgment task without the referent tone, whereas participants in the referent group did the task with it. Timbre-to-response mapping was counterbalanced across participants.

Participants were instructed to press one key when a piano tone was presented and the other key when a violin tone was presented, as quickly as possible while maintaining high accuracy. A red colored word "Incorrect" was given for 500 ms as feedback at the center of the screen when an incorrect response was made.

Results

Sixty out of 7,680 trials (0.78%) were removed from analysis using the same RT cutoff criteria as in Experiment 1. Mean correct RT and PE were calculated for each participant as a function of SMARC mapping (see Table 1). ANOVAs were conducted on the mean RT and PE data, with SMARC mapping (high–right/low–left and high–left/low–right) as a within-subjects variable, and referent (referent tone and no referent tone) and group (musician, nonmusician) as between-subjects variables.

RT. The musicians (M = 530 ms) tended to respond faster than the nonmusicians (M = 561 ms), but the main effect of group was not significant, $F(1, 60) = 2.26$, $p = .138$, $MSE = 67{,}038$, $\eta_p^2 = 0.04$. The main effect of SMARC mapping was significant, though, $F(1, 60) = 7.57$, $p = .008$, $MSE = 4{,}860$, $\eta_p^2 = 0.11$, indicating a 15-ms high–right/low–left advantage. More important, the interaction between SMARC mapping and referent was also significant, $F(1, 60) = 4.82$, $p = .032$, $MSE = 4{,}860$, $\eta_p^2 = 0.03$ (see Figure 2). The SMARC effect was 27 ms when the referent tone was present, $F(1, 30) = 10.33$, $p = .003$, $MSE = 5{,}759$, $\eta_p^2 = 0.19$, and a nonsignificant 3 ms when it was not, $F < 1$. The interaction of SMARC mapping, referent, and group was not significant, $F(1, 60) = 1.76$, $p = .190$, $MSE = 4{,}860$, $\eta_p^2 = 0.07$. However, separate analyses showed that the SMARC mapping × Referent interaction was significant for the nonmusicians, F(1,

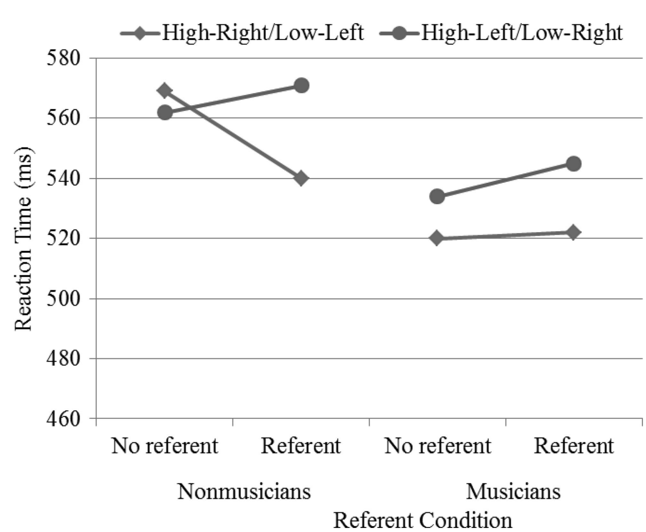

Figure 2. Mean reaction time as a function of SMARC mapping, referent and group in Experiment 2.

30) = 6.16, p = .019, MSE = 4,899, η_p^2 = 0.17, but not the musicians, F < 1.0 (see Table 1). Whereas the nonmusicians showed no SMARC effect (– 7 ms) without a referent tone, they showed a 31-ms effect when the referent tone was provided. In contrast, the musicians showed a 14-ms SMARC effect without a referent tone and only a nonsignificant increase to 23 ms when the referent tone was provided. No other term was significant, Fs < 1.

PE. Overall PE was 5.51%. The main effect of SMARC mapping was significant, F(1, 60) = 12.38, p = .0008, MSE = 167, η_p^2 = 0.17, indicating a 3.17% high–right/low–left advantage. No other main effect or interaction was significant (Fs < 1.05).

Discussion

The results with no referent tone were similar to those reported by Lidji et al. (2007), who found an 18-ms SMARC effect for musicians and a 2-ms, nonsignificant, effect. The major new finding is that nonmusicians, as well as musicians, showed a SMARC effect when the referent tone was provided. The findings of this experiment demonstrate that, for nonmusicians, when pitch is irrelevant, the correspondence effect between pitch height and lateralized responses occurs in the RT data when pitch height can be coded relative to another tone but not otherwise. That is, when the referent tone was given, tone pitch was automatically coded relative to it, but when no referent tone was given, the tone pitch was not coded. This result is in contrast to that for musicians, for whom a referent tone is not required.

Although none of the nonmusicians in Experiment 2 was currently receiving musical training, they had trained on a musical instrument (piano or violin) for 3.5 years on average. Thus, one might argue that this amount of training could have caused the SMARC effect. However, if the significant effect is due to the amount of training they had received, a SMARC effect should have also been evident when no referent was provided, as it was for the musicians. That, for nonmusicians, the SMARC effect was modulated by the presence or absence of the referent tone indicates the importance of the relative code for pitch height in the SMARC effect, as implied by the polarity correspondence account.

Experiment 3: Color-Judgment Task

Experiment 2 showed that, for nonmusicians, the SMARC effect occurred in the presence of a referent tone but not otherwise for a task in which pitch height was irrelevant but a property of the tone, its timbre, was still relevant. In Experiment 3, we examined the role of a referent for the SMARC effect for a task like that used by Nishimura and Yokosawa (2009) in which judgments were based on the color of a visual stimulus and tone pitch was completely irrelevant to the task. We presented the tones binaurally, rather than monaurally with location varying, as in their study, so that the conditions would be more similar to those of our Experiments 1 and 2. Nonmusicians performed the color-judgment task, with a high- or low-pitch tone presented as an accessory stimulus. Half of the participants performed the color-judgment task with a referent tone and the other half without a referent tone. If pitch height is coded automatically relative to the referent tone but not otherwise, then the SMARC effect should be evident when the referent tone is provided than when it is not.

Method

Participants. Thirty-two new undergraduates (male: 18, female: 14) at Korea University, all nonmusicians, participated in partial fulfillment of a course requirement. All were right handed and had normal or corrected-to-normal visual acuity and auditory capacity, as determined by self-report. Seven had no prior musical experience; the other 25 had an average of 4.19 years of musical training, which had stopped at 12.0 years of age on average. Participants were randomly assigned to two different groups: referent and no referent.

Apparatus, stimuli, and procedure. Apparatus, stimuli, and procedure were identical to Experiment 2, except as noted. The imperative stimuli were red and green crosses (0.5 cm × 0.5 cm, 0.4° × 0.4°) which were accompanied by task irrelevant high (1,000 Hz) or low (250 Hz) pitch pure tones. The fixation row was horizontally arrayed three Xs (0.5 cm × 0.5 cm, 0.4° × 0.4° for each X) on a dark background. A 500-Hz pure tone was used as a referent tone.

Participants were instructed to press the left or right key to the color of the stimuli while ignoring the high- or low-pitched tone. The participants in the no referent group performed the color-judgment task without the referent tone, and the participants in the referent group did the task with it. At the beginning of each trial, the fixation was presented at the center of the screen. For the referent group, the referent tone was given simultaneously with the fixation row, but not for the group with no referent. Participants were instructed to stare at the fixation row. After 500 ms, the fixation row changed to a colored cross. At the same time, the high (1,000-Hz) or low (250-Hz) pitch tone was given bilaterally through headphones for 500 ms. The colored cross remained on the display until a response was made. Participants were told to make a left or right key-press response to the color of the cross. A white "Incorrect" was given for 500 ms as feedback at the center of the screen when an incorrect response was made. The fixation row for the next trial appeared on 1,000 ms after the correct response or the error feedback.

Results

Two trials out of 3,840 trials (<1.0%) were removed using the same RT cutoff criteria as in Experiments 1 and 2. Mean correct RT and PE were calculated for each participant as a function of SMARC mapping (see Table 1). ANOVAs were conducted on the mean RT and PE data, with SMARC mapping (high–right/low–left and high–left/low–right) as a within-subject variable and referent (referent tone and no referent tone) as a between-subjects variable.

RT. A 5-ms overall SMARC mapping effect was obtained, F(1, 30) = 9.34, p = .005, MSE = 49.43, η_p^2 = 0.24. Most important, the interaction of SMARC mapping and referent was significant, F(1, 30) = 10.55, p = .003, MSE = 49.43, η_p^2 = 0.26 (see Figure 3). A significant SMARC effect of 11 ms was obtained when the referent was given, F(1, 30) = 19.87, p = .0001, MSE = 49.43, η_p^2 = 0.40, but no effect was obtained when it was absent, F < 1. The main effect of referent was not significant, F < 1.

PE. Overall PE was 0.49%. PE was 0% with the referent tone and 1% without it, yielding a main effect of referent, F(1, 30) = 6.99, p = .013, MSE = 2.24, η_p^2 = 0.19. Due to the lack of errors for either mapping with the referent tone, both the SMARC map-

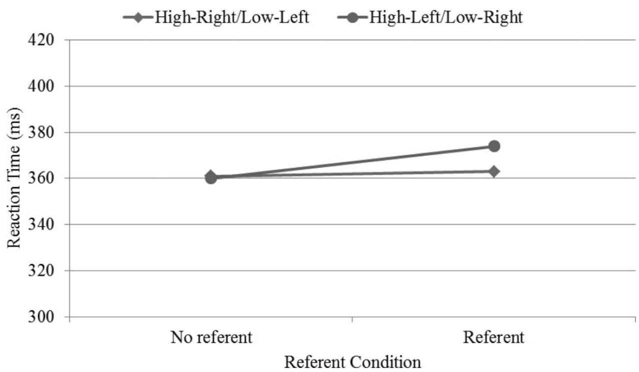

Figure 3. Mean reaction time as a function of SMARC mapping and referent in Experiment 3.

ping main effect and the interaction of SMARC mapping and referent produced the same, nonsignificant, *F* ratios, $F(1, 30) = 2.93$, $p = .097$, $MSE = 1.20$, $\eta_p^2 = 0.09$. Because the condition with no referent tone showed a tendency toward a SMARC effect in PE, we conducted an ANOVA of just that condition, and the difference between the two mappings was nonsignificant, $F(1, 15) = 2.93$, $p = .108$, $MSE = 2.4$. We disregard this difference because of its nonsignificance, coupled with the inability to analyze errors in the condition with a referent tone due to their not occurring.

Discussion

As in Experiment 2, the SMARC effect was evident only when participants performed the color-discrimination task with a referent tone. An 11-ms high–right/low–left advantage was obtained when the referent tone was provided, but no such effect was evident without a referent tone, indicating that the SMARC effect is due to correspondence between the relative code for pitch height and the response code. That is, the referent tone played a crucial role in the SMARC effect when the tone was completely task irrelevant. If the SMARC effect were based on the spatial–musical associations formed through early musical training, it should have been found regardless of whether the referent tone was provided.

The results of this experiment differ from Nishimura and Yokosawa's (2009) finding of a significant 8-ms SMARC effect without a referent tone. Among the differences in methods, the following are two possible sources of the discrepant results. Their participants apparently had more musical experience than ours, having 9 years of compulsory musical education and up to 15 years of additional musical experience, although their data showed no correlation of amount of musical experience with SMARC effect size. Also, the tone was presented binaurally in our Experiment 3 but monaurally, varying randomly between the left and right ears, in Nishimura and Yokosawa's experiment. Their results showed a spatial Simon effect based on tone laterality, indicating that tone location was coded and that attention was likely drawn to the tone (e.g., Spence & Driver, 1997). Attending to the tone could have led some participants to code pitch height categorically, as they would if pitch height were relevant to the task. Whether these methodological differences or others are responsible for the discrepant results will have to be determined by future research. The main point of our experiment is that, again, when tone pitch was irrelevant, a SMARC effect was obtained in the presence of a referent tone but not in its absence. Thus, when conditions are such to induce categorical coding of the pitch height as high or low, an irrelevant tone produces a SMARC effect for nonmusicians.

General Discussion

Primary Outcomes

In previous studies, nonmusicians exhibited a SMARC effect with left–right responses when tone pitch was relevant to the task but not when timbre was relevant and pitch irrelevant (Lidji et al., 2007; Rusconi et al., 2006). However, the tasks were conducted such that a referent tone was provided for the former but not the latter. The purpose of the present study was to dissociate the influence of a referent tone on the SMARC effect from the task relevancy variable. In Experiment 1, for which pitch height was relevant to the task, the SMARC effect occurred both when a referent tone was present and when it was not. This result indicates that pitch height was coded categorically even without a referent tone, which is not surprising because such categorization is required for the pitch-discrimination task.

In contrast, in Experiment 2, where lateralized responses to the timbre of the target tone were made, nonmusicians showed a 31-ms SMARC effect when the referent tone was provided prior to onset of the target tone but no SMARC effect when the referent was absent. Thus, when pitch height was irrelevant to the task, the SMARC effect occurred only in the presence of a referent tone. This result provides evidence that tone pitch was implicitly coded as low or high when the tone immediately followed a referent. In contrast, the group of musicians showed a SMARC effect that did not interact significantly with whether there was a referent tone. The musicians apparently coded pitch height automatically in the absence of a referent tone.

The role of the referent tone for nonmusicians was also evident in Experiment 3, in which they performed a color-discrimination task with a tone presented as an accessory stimulus. Results showed a significant 11-ms SMARC effect when the referent tone was present but no SMARC effect when the referent was absent. This result converges with that for nonmusicians in Experiment 2 to show that when the pitch of the target tone is task irrelevant, the relative code for pitch height is implicitly formed relative to the referent tone but not otherwise. These results indicate that the SMARC effect depends on participants' ability to form the relative code for pitch height rather than on their ability to use an external instrument with which they are familiar as a referent dimension for coding pitch height in the horizontal dimension, as Lidji et al. (2007) suggested.

The finding that musicians showed a horizontal SMARC effect for conditions without a referent tone in Experiment 2 and other studies when judging a tone dimension other than pitch height implies that they implicitly form categorical pitch codes without a referent for comparison. Like experts in other domains, expert musicians have the ability to perceive, process, and memorize material relevant to the field in which they have practiced (Chaffin & Imireh, 2002). The musical training they have received could be expected to increase their ability to process pitch height efficiently on the basis of their musical knowledge. Musicians could have mental representations for every possible target tone. Thus, when performing a timbre-judgment task, expert musicians could have formed the categorical code for pitch height based on their memory for the other target tones with no explicit referent tone, resulting in a correspondence effect between pitch height and response location.

SMARC and Orthogonal SRC Effects

As noted, it has been suggested that the SMARC effect with lateralized responses may be a type of orthogonal SRC effect (Lidji et al., 2007; Nishimura & Yokosawa, 2009; Rusconi et al., 2006). Specifically, the advantage for the high–right/low–left mapping bears similarity to the advantage for the up–left/down–right mapping that is often obtained with a variety of visual stimuli and manual responses (e.g., Cho & Proctor, 2002, 2004; Lippa, 1996; Weeks & Proctor, 1990). This up–right/down–left advantage also has been found when stimulus location is task irrelevant, a finding called the orthogonal Simon effect (Cho, Proctor, & Yamaguchi, 2008; Nishimura & Yokosawa, 2006). The analogous findings for the correspondence effects of pitch height to left and right responses and vertical location to left and right responses suggest that the underlying mechanism that produces the effects are the same.

The most strongly supported account of the up–right/down–left advantage is the polarity correspondence account (Cho & Proctor, 2003; Lippa & Adam, 2001; Proctor & Cho, 2006), according to which, in two-choice tasks, one alternative for each spatial dimension is coded categorically as + polarity (or unmarked) and the other as – polarity (or marked; e.g., Clark, 1973; Seymour, 1974). For the vertical dimension, "up" is coded as + polarity and "down" as – polarity, whereas for the horizontal dimension "right" is coded as + polarity and "left" as – polarity (e.g., Clark & Chase, 1972; Olson & Laxar, 1973; Seymour, 1974). The up–right/down–left relation maintains correspondence of the polarities for the stimulus and response categorical codes, whereas the alternative mapping does not.

This polarity correspondence account provides a straightforward explanation of the SMARC effect obtained with a horizontal response set. When pitch is relevant, as in Experiment 1, the high pitch tone is coded as + polarity and the low pitch tone as – polarity, and these polarities correspond to those of the right (+) and left (−) responses when the mapping is high–right/low–left. The timbre-judgment task is analogous to the orthogonal Simon effect, obtained when vertical stimulus location is irrelevant, with responses benefiting from correspondence of the + and – code polarities, even though the dimension (vertical location in the case of the orthogonal Simon effect and pitch height in the case of the SMARC effect) is irrelevant. When irrelevant, the categorical pitch codes along the vertical dimension are formed by musicians automatically, due to their extensive musical experience, regardless of whether a referent tone is provided. However, nonmusicians need a context, provided by the referent tone, which causes the irrelevant pitch height to be coded. Thus, in this view, the absence of the SMARC effect for nonmusicians when pitch height is irrelevant is because they do not code the pitch categorically on the vertical dimension, and not because they fail to code pitch along the horizontal dimension (e.g., due to lack of familiarity with the piano keyboard).

It has been suggested that pitch representation is multidimensional (Mudd, 1963; Rusconi et al., 2006). Lidji et al. (2007) proposed that pitch of a tone is spatially represented differently on the basis of the response set. According to them, the SMARC effect is due to the vertically and horizontally oriented spatial representations of pitch. When the responses are made with a vertically arrayed response set, the pitch of the tone automatically activates an "up" or "down" spatial code via the association between pitch and space. However, when the responses are made with a horizontally arrayed response set, the automatic activation of "left" or "right" code is mediated by knowledge of music. That nonmusician participants showed a SMARC effect in Experiment 2 when making lateralized responses to the timbre of the target, as long as the referent tone was provided, indicates that whether the correspondence effect occurs between the pitch of the target and lateralized response depends on participants being able to form the relative codes for the pitch and not necessarily on their knowledge about music.

It is unlikely that the dimension of the response set determines whether pitch height is represented vertically or horizontally, as Lidji et al. (2007) have suggested. Not only is the dimension of pitch called "height," but the referent tone used in the present experiments served the purpose of allowing the tones to be coded as high or low relative to it, not left or right. Rather, the nature of the categorical coding of pitch is likely vertical, regardless of whether the response set is vertical or horizontal, but different aspects of the target stimulus are preferentially processed on the basis of the task instructions and the response-set dimension. More specifically, when the response set is vertical, the vertical aspect of the target tone stimulus seems to be favorably processed regardless of whether pitch height is task relevant or not: The vertical SMARC effect occurs even when up and down responses are made to a dimension of the target stimulus other than pitch. However, when the response set is horizontal, the vertical aspect of the target stimulus seems to be categorically coded only when the pitch is task relevant or the relative pitch height is made salient by the task environment: The horizontal SMARC effect occurs when the verticality is task relevant or when a referent is presented relative to which pitch height is coded categorically.

Conclusion

The present study shows that the horizontal SMARC effect can be obtained for nonmusicians when pitch height is coded categorically. The results imply that when the categorical polarity code for pitch height is formed relative to a referent it automatically activates the horizontal response code of corresponding polarity, yielding the SMARC effect. It should be noted that SRC effects have been obtained with various stimulus dimensions having a property of being categorically ordered, such as numbers, time, and linguistic sequence, combined with a horizontally arrayed response set (e.g., Bae, Choi, Cho, & Proctor, 2009; Schwarz & Keus, 2004). It has been widely accepted that these SRC effects are based on a left-to-right ordered mental representation of these stimulus dimensions (e.g., Dehaene, Bossini, & Giraux, 1993). However, the findings of the present study with regard to the SMARC effect are more consistent with an alternative view that polarity correspondence for categorical codes across different dimensions (e.g., Proctor & Cho, 2006), rather than coding of stimuli along a horizontal dimension that matches the horizontal response dimension, is the basis for many of these effects. As Nishimura and Yokosawa (2009) noted, the SMARC effect along with other phenomena involving "nonhorizontal stimulus features on horizontal responses may be explained within a single theoretical framework (see Proctor & Cho, 2006), at least to a large extent" (p. 670), that of polarity correspondence that occurs as a consequence of categorical coding.

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