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Mental representation: What can pitch tell us about the distance effect?

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ABSTRACT

Reaction time (RT) profiles for comparing magnitudes (e.g., numbers, physical sizes) are similar – the larger the difference between the compared stimuli, the shorter the RT (distance effect). Nevertheless, it is unclear whether such correspondence is due to similar, two-dimensional, linear mental representations of magnitudes. In contrast, pitch perception has a more complex, two-dimensional, helical representation. This study examined whether comparisons of music pitches are similar to other magnitude response functions. Experiment 1 employed a comparison task, resulting in an RT profile identical to that obtained when comparing other magnitudes. In contrast, Experiment 2 employed a discrimination task, resulting in RTs that matched the helical representation and were dissociated from the classical distance effect. Experiment 3 replicated the results of Experiment 1 using a comparison task with different stimuli and intervals. These findings imply that the distance effect under comparison tasks might reflect a general sensorimotor transformation, rather than mental representation per se.

The question whether the human brain processes magnitude via a general mechanism, or rather by distinct, specialized mechanisms (Cohen Kadosh and Henik, 2006; Cohen Kadosh et al., 2005, 2007b, 2007c, in press-b; Dormal et al., 2006, 2008, this issue; Fias et al., 2003; Kaufmann et al., 2005; Moyer and Landauer, 1967; Pinel et al., 2004; Schwarz and Heinze, 1998; Walsh, 2003) has been the topic of a long-standing debate. For a recent review and meta-analysis see Cohen Kadosh et al. (in press-a). Recently, Walsh (2003) proposed ''A Theory of Magnitude'' (ATOM), which suggests that the processing of time, space and quantity are carried out by a single mechanism in the parietal lobes. Indeed, the reaction time (RT) profiles for comparing different magnitudes, such as numbers, physical sizes, and luminance yield similar functions. Namely, the larger the difference between the compared stimuli, the shorter the RT (i.e., the distance effect) (Cohen Kadosh and Henik, 2006; Cohen Kadosh et al., 2005; Fias et al., 2003; Kaufmann et al., 2005; Moyer and Landauer, 1967; Pinel et al., 2004). Moreover, brain imaging data have provided converging evidence for a common mechanism for magnitudes by revealing a spatial overlap between different types of comparisons (Fias et al., 2003), and their distance effects in the left posterior intraparietal sulcus (IPS) (Cohen Kadosh et al., 2005).

Another effect that is not restricted to numbers is the SNARC effect (spatial numerical association of response codes) (Dehaene et al., 1993; Fias and Fischer, 2004; Gevers

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and Lammertyn, 2005). The SNARC effect summarizes the often reported phenomenon that responding to small numbers is faster with a left keypress, while responding to large numbers is faster with a right keypress. The discovery of the SNARC effect led researchers to suggest that numbers are represented on a horizontal mental number line from left to right. However, recently, the existence of a vertical SNARC effect (Ito and Hatta, 2004; Schwarz and Keus, 2004) has been demonstrated. Moreover, it has been shown that responding is facilitated by assigning bottom-left response keys to small numbers and upper-right response keys to large numbers (Gevers et al., 2006). It is interesting to note that a similar effect is observed when participants compare time; left side responses to early onset timing are faster than those to late onset timing, whereas right side responses to late onsets are faster than those to early onsets (Ishihara et al., 2008, this issue). Importantly, similar effects to the SNARC are also observed when participants compare pitch – an effect which has been termed SMARC (spatial musical association of response code). Responding to a lower pitch is faster with a left or lower key, whereas responding to a higher pitch is faster with a right or upper key (Rusconi et al., 2006). One might assume that such findings reflect keyboard instrument bias (piano and xylophone) whereby pitch height corresponds to right-plane movement. However, not all keyboards reflect this spatial arrangement (such as an accordion). A few string instruments do not conform to the typical low-to-high, left-to-right, down-to-up relationship (e.g., cello and double bass), as well as most valve-controlled brass wind instruments (such as trumpet and French horn). Importantly, in both the SNARC and the SMARC the spatial response can be primed by magnitude, even when it is irrelevant to the task (parity judgment task, e.g., Dehaene et al., 1993; classification of sounds as being produced by wind or percussion instruments, Rusconi et al., 2006), hence, demonstrating that the extraction of magnitude information is automatic.

The SMARC result is surprising since, in contrast to numbers (or time, physical size, etc.), it is a commonly held view that pitch has a more complex, two-dimensional, helix shaped representation. This representation is composed of a spiral (representing pitch chroma) and a vertical plane (representing pitch height) (Ueda and Ohgushi, 1987). Recently, this representation for pitch has been supported by a functional magnetic resonance (fMRI) study: pitch chroma was found to modulate anterior temporal lobe activity while pitch height was subserved by the posterior temporal lobe (Warren et al., 2003).

The surprising similarity between the SMARC and the SNARC effects can be also explained by stimulus saliency per se (e.g., the greater, bolder, larger, longer, or louder the stimulus is) and not necessarily the similarity in the mental representation. It has been found that the more salient the feature, the faster the response with a right/upper key rather than a left/lower key (Cho and Proctor, 2003). Such an explanation might be valid for the SNARC, SMARC and SNARC-like effects for other dimensions that are based on an order scale, such as days of the week, months, letters (Gevers et al., 2004, 2003), or time (Ishihara et al., 2008, this issue). In addition, we would like to suggest that finding distance effects for a variety of dimensions might be due to either similarity in the mental representation, which is based on a linear continuum (i.e., from less to more), or perhaps due to the utilization of a similar magnitude comparison mechanism, or response selection, which are representation independent.

In the current study, we employed pitch comparison in order to examine if the response function is similar to response functions of other magnitudes. In the case of a general comparison mechanism, pitch would yield similar distance effects as found for other dimensions. In contrast, if a comparison task reflects a mental representation (e.g., in previous studies the mental representation of numbers, and in the current study the helical representation of pitch), the RT profile for pitch will differ from the ones obtained for other magnitudes.

1. Experiment 1

We employed a comparison task in which participants indicated whether the second note in a pair was higher or lower than the first.

1.1. *Method*

1.1.1. *Participants*

Twelve right-handed participants, mean age = 22.5 years, SD = 1.98, 4 males, with little to no formal music education (mean = 1.83 years, SD = 2.37). The study was approved by the local ethics committee. All the participants were recruited from an academic environment. Informed consent to participate was obtained from all participants.

1.1.2. *Stimuli*

Complex tones (i.e., music pitches) were recorded from a *Technics* SX-P50 88-key electric piano (with full-size weighted keys) directly into a *Korg* D1600 16-channel digital recording station. All sound (wav) files were edited for length and loudness (i.e., reduced or enhanced where necessary) with the Soundforge XP V4.5 (Sonic Foundry) sound-editing package. The stimuli were presented via a desktop PC (Intel Pentium 3 processor, 862 MHz), with an intel(R) integrated audio card, over standard PC-speakers at a comfortable (70 dB) listening level. The experiment used four types of pitch distances (in order to keep the same terminology as in the literature of magnitude comparison, we use the term "distance" to indicate "interval"): 2 semitones ($F\#_3$–$G\#_3$ and $F\#_4$–$G\#_4$); 11 semitones (G_3–$F\#_4$ and A_3–$G\#_4$); 12 semitones (which differ only in height, G_3–G_4 and A_3–A_4); and 13 semitones ($F\#_3$–G_4 and $G\#_3$–A_4). These distances were chosen based on how the music pitches could be combined. Namely, we tried to avoid the condition whereby a particular pitch would appear exclusively in a distance. The music pitches $F\#_3$, G_3, $G\#_3$, A_3, $F\#_4$, G_4, $G\#_4$, and A_4 corresponded to the following frequencies (in Hz): 185.35, 196.66, 207.92, 220.38, 370.70, 393.32, 415.84, and 440.76, respectively. Each distance was randomly presented and appeared 24 times.

1.1.3. *Procedure*

Each trial began with an asterisk as a central fixation point, presented for 1 sec at the center of a computer screen, followed by a first tone for 1 sec. Three hundred milliseconds after the first tone decayed, a second tone was sounded for 1 sec, and had to be compared to the first tone. Participants were asked to decide whether the second tone was higher or lower than the first one, and to indicate their decision by pressing one of two keys (P or Q) on a keyboard. RTs were calculated from the onset of the second tone. A visual feedback for 500 msec followed responding and indicated whether the decision was correct or not. Participants used the fingers of their left and right hands to press the P or Q keys. The assignment of P/Q response keys to higher/lower tones was counterbalanced across participants in an effort to offset SNARC effects and spatial perceptual biases (low-to-high/left-to-right associations). In addition, half of the distances were presented in an ascending order and the other half in a descending order. Each session included 96 trials (i.e., 4 distances × 2 pitch combinations × 2 orders (ascending/descending) × 6 repetitions). An experimental block was preceded by 16 practice trials.

1.1.4. Design

The manipulated variable was pitch distance (2, 11, 12, or 13 semitones).

1.2. Results

For every participant in every condition mean RT was calculated for correct trials only. These means were subjected to a one-way analysis of variance (ANOVA) with distance as within-subject factor.

The main effect of distance was significant [$F(3,33) = 20.29$, MSE = 15,868, $p < .001$]. That is, participants responded faster to a large pitch distance than to a small pitch distance (1115 msec for distance 2; 876 msec for distance 11; 783 msec for distance 12; and 754 msec for distance 13). Planned comparisons revealed that the difference between distance 2 and distance 11 [$F(1,11) = 36.82$, MSE = 9295, $p < .001$], as well as the difference between distance 11 and distance 12 [$F(1,11) = 5.97$, MSE = 8723, $p < .05$], was significant. In contrast, the difference between distance 12 and distance 13 was not significant [$F(1,11) = 1.15$, MSE = 4362, ns]. A trend analysis revealed that a linear trend explained 85% of the variance and gave the best fit [$F(1,11) = 21.59$, MSE = 38,442, $p < .001$] (Fig. 1). Moreover, when we modified the weights (i.e., from −3, −1, 1, 3 to −7.5, 1.5, 2.5, 3.5) for the non-linear distances that we presented (i.e., 2, 11, 12, 13), the trend analysis explained 97.4% of the variance [$F(1,11) = 26.35$, MSE = 35,731, $p < .001$]. In contrast, a trend analysis that reflected two-dimensional representation of music pitch (weights equal −1, 1, −1, 1 for 2, 11, 12, and 13 semitones, respectively) was significant, but explained only 22% of the variance [$F(1,11) = 27.57$, MSE = 7807, $p < .001$].

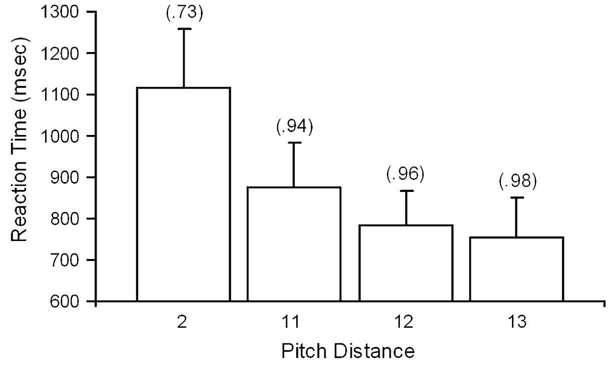

Fig. 1 – RT and accuracy rate (in parentheses) in Experiment 1, as a function of distance. Error bars depict one standard error of mean (SEM).

Analysis of the errors revealed a main effect of distance [$F(3,33) = 62.04$, MSE = .002, $p < .001$]. Error rates increased with distance (.27, distance 2; .06, distance 11; .04, distance 12; .01, distance 13). Planned comparisons revealed that the only significant differences were between distance 2 and distance 11 [$F(1,11) = 138.93$, MSE = .001, $p < .001$], and distance 11 and distance 13 [$F(1,11) = 5.66$, MSE = .002, $p < .05$]. In addition, the correlation between RT and errors was significantly positive [$r(4) = .98$, $p < .05$], thus excluding any RT-accuracy trade-off.

1.3. Discussion

The results showed the classical distance effect that has already been observed with other magnitudes (Cohen Kadosh and Henik, 2006; Cohen Kadosh et al., 2005; Fias et al., 2003; Kaufmann et al., 2005; Moyer and Landauer, 1967; Pinel et al., 2004). That is, the smaller the distance between the pitches, the slower the RT. Such a result is surprising, given the difference between the mental representation of pitch (two-dimensional) and other magnitudes (one-dimensional), and the distinct neuronal correlate for pitch (temporal lobe) and magnitude (parietal lobe). One possibility is that the current pattern was a result of a ''mental walk'' on the helix. In other words, pitch is represented linearly, and not two-dimensionally as is believed (Ueda and Ohgushi, 1987). Hence, distance 2 yielded the slowest RT while distance 13 yielded the fastest one, resulting in a linear trend of the RT profile.

Experiment 2 was conducted in order to clarify the relationship between the mental representation of music pitch and the distance effect by using an alternative task; that is, instead of a comparison task we employed a same–different task. Previous studies in the field of numerical cognition have shown that a distance effect is also observed under such a task (Dehaene and Akhavein, 1995; Verguts and Van Opstal, 2005). Others suggested that a same–different task can eliminate any systematic confounding factors related to magnitude and reflect a more automatic mental representation than the one that is used under a magnitude comparison task (Tzelgov and Ganor-Stern, 2004). Namely, it was suggested that in order to learn about basic features of mental representations one should employ paradigms in which the involvement of intentional strategies is minimal. Therefore, one should use a task in which the processing of the mental entities in question is automatic in the sense of not being part of the task requirements (e.g., Cohen Kadosh et al., 2007a, 2008a, 2008b; Tzelgov and Ganor-Stern, 2004). Accordingly, a non-comparison task, such as a same–different task, seems ideally fitted for testing the relationship between the mental representation and the distance effect. In a same–different task the participants are required to compare the tones according to their physical similarity, and hence are not biased to use pitch height or chroma, which might lead to the linear pattern of pitch observed in Experiment 1. If the distance effect observed in Experiment 1 reflects the mental representation in general, and a true linear mental representation of pitch in this particular case, we would expect the same linear pattern in the current task as well. However, it might be that the result of Experiment 1 was task-specific; hence, by employing an indirect task such as a same–different task, we would be able to eliminate any systematic confounding factors related to magnitude, subsequently leading to a clearer examination of the mental representation of music pitch.

2. Experiment 2

2.1. *Method*

2.1.1. *Participants*

Fifteen participants (14 right-handed, 11 females), mean age = 23.4 years, SD = 1.72, with no formal musical education (mean = .86 years, SD = 1.8). None of the participants took part in Experiment 1.

2.1.2. *Stimuli*

We used the same stimuli as in Experiment 1 to create pairs for the *same* and *different* pairs' conditions. Namely, for the same condition, each tone from the different pairs' condition appeared as the first and second tone (e.g., A_3 after A_3, G#$_4$ after G#$_4$); for the different pairs we used the same pairs as in Experiment 1 (e.g., A_3–G#$_4$). The ratio of same–different trials was 1:1. As in Experiment 1, for the different condition, each distance appeared 24 times.

2.1.3. *Procedure*

The participants were asked to compare the two tones by pressing one of two keys on a computer keyboard (P or Q), using the fingers of their left and right hands. The P and Q keys represented "same" or "different" responses, and were counterbalanced across participants. Each session included 192 trials. Each experimental block was preceded by 32 practice trials. Aside from the above, all other features of the experiment were identical to Experiment 1.

2.1.4. *Design*

The manipulated variable was pitch distance (0, 2, 11, 12, or 13 semitones). However, for the analysis, we excluded the same condition (i.e., 0 semitone, which was used as a filler) and included only the different condition (i.e., 2, 11, 12, or 13 semitones).

2.2. *Results*

For every participant in every condition mean RT was calculated for correct trials only. These means were subjected to a one-way ANOVA with distance as a within-subject factor.

The mean RT for the same condition was 640 msec, and the error rate was 1.8%. The main effect of distance was significant [$F(3,42) = 4.33$, MSE = 3349, $p < .01$]. That is, participants responded faster to tones that differed by 11 semitones (642 msec) or 13 semitones (634 msec) than to tones that differed by 2 semitones (702 msec) or 12 semitones (673 msec). Planned comparisons showed significant differences between distance 2 and distance 11 [$F(1,14) = 8.98$, MSE = 3013, $p < .01$], distance 2 and distance 13 [$F(1,14) = 7.01$, MSE = 4948, $p < .05$], distance 12 and distance 13 [$F(1,14) = 5.43$, MSE = 2083, $p < .05$], and a marginal difference between distance 11 and distance 12 [$F(1,14) = 3.73$, MSE = 1919, $p = .07$]. Notably, there was no difference between comparisons of 11 versus 13 semitones [$F < 1$], or 2 versus 12 semitones [$F < 1$]. Note that in Fig. 1 (i.e., Experiment 1) RT declines with distance whereas in Fig. 2 (i.e., Experiment 2) RT does not change in a linear fashion with distance. Accordingly, a trend analysis with the weights −1, 1, −1, and 1 for 2, 11, 12, and 13 semitones explained 84% of the variance and gave the best fit [$F(1,14) = 19.13$, MSE = 1918, $p < .001$]. In contrast, the linear trend explained only 51% of the variance and only approached the significant level [$F(1,14) = 4.04$, MSE = 5555, $p = .06$].

Analysis of the errors revealed a main effect of distance [$F(3,42) = 4.85$, MSE = .002, $p = .005$]. In contrast to Experiment 1, error rates did not increase with distance, but showed a similar function to the RT (.07, distance 2; .02, distance 11; .03, distance 12; .02, distance 13). The differences that were observed in the RT data were not significant in the error rates analysis, aside from the significant difference between distance 2 and the other distances [$F(1,14) = 6.31$, MSE = .005, $p < .05$]. In addition, the correlation between RT and errors approached significant [$r(4) = .93$, $p = .06$], thus excluding any RT-accuracy trade-off.

2.3. *Discussion*

The results of Experiment 2 did not replicate the results of Experiment 1. Namely, RTs did not decrease as a function of the pitch distance. Rather, they were modulated by differences in height and chroma; distance 2 (which differs minimally in chroma), and distance 12 (which differs only in height), were significantly slower than distance 11 (which substantially differs in chroma) and distance 13 (which differs in both chroma and height). Thus, the results reflected the two-dimensional representation of music pitch. In contrast, previous studies in the field of numerical cognition have shown that the classical distance effect is also observed under a same–different task (Dehaene and Akhavein, 1995; Verguts and Van Opstal, 2005). That is, Dehaene and Akhavein (1995) showed that

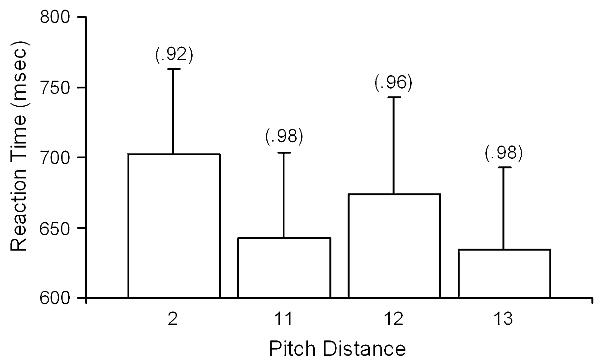

Fig. 2 – RT and accuracy rate (in parentheses) in Experiment 2, as a function of distance. Error bars depict one SEM. Note the different scaling range from Fig. 1.

when participants had to decide whether a pair of digits was perceptually the same (2-2) or different (2-8), the typical distance effect was observed both with small (between 1 and 9, see also Verguts and Van Opstal, 2005, for similar results) or large numbers (up to 80).

In light of these results, one could probably interpret the findings of Experiment 1 to be stimuli-specific. To rule out such a possibility, we conducted Experiment 3.

3. Experiment 3

In Experiment 1 the magnitudes in semitones of the different distances were not equivalent (e.g., 2 *vs* 11 semitones, 11 *vs* 12 semitones). In order to examine whether the linear trend obtained was due to the specific intervallic distances employed, Experiment 3 utilized music pitches of equal distances (e.g., 4, 8, 12, and 16 semitones). Hence, in contrast to Experiment 1, the distances in the current experiment were equidistant.

3.1. Method

3.1.1. Participants

Nine participants (8 right-handed, 8 females), mean age = 24.03 years, SD = 2.8, with little or no formal music training (mean = 1.43 years, SD = 1.98). None of the participants took part in Experiment 1 or 2.

3.1.2. Stimuli

The stimuli employed were pitches C_3, $D\#_3$, E_3, G_3, $G\#_3$, A_3, B_3, C_4, $D\#_4$, E_4, G_4, $G\#_4$, A_4, and B_4, which corresponded to (in Hz) 130.81, 155.56, 164.81, 196.66, 207.92, 220.38, 246.94, 261.63, 311.13, 329.63, 393.32, 415.84, 440.76, and 493.88, respectively. We used these pitches to create the following pairs: 4 semitones (C_3–E_3, $D\#_3$–G_3, C_4–E_4 and $D\#_4$–G_4); 8 semitones (C_3–$G\#_3$, $D\#_3$–B_3, C_4–$G\#_4$ and $D\#_4$–B_4); 12 semitones (C_3–C_4, $G\#_3$–$G\#_4$, G_3–G_4 and A_3–A_4); and 16 semitones (C_3–E_4, $D\#_3$–G_4, G_3–B_4 and E_3–$G\#_4$). Each distance appeared 24 times. Aside from the above pitch set, all other features of the experiment were identical to Experiment 1.

3.2. Results

For every participant in every condition mean RT was calculated for correct trials only. Two participants were excluded from the analysis due to more than 50% errors among pairs with pitch differences. These means were subjected to a one-way ANOVA with distance as a within-subject factor.

The main effect of distance was significant [$F(3,18) = 10.7$, MSE = 17,095, $p < .001$]. That is, participants responded faster to larger pitch distances than to smaller ones: 4 semitones = 1259 msec; 8 semitones = 1131 msec; 12 semitones = 968 msec; and 16 semitones = 901 msec. Planned comparisons revealed a marginal difference between distance 4 and distance 8 [$F(1,6) = 4.23$, MSE = 13,654, $p = .08$], and a significant difference between distance 8 and distance 12 [$F(1,6) = 30.01$, MSE = 3108, $p = .001$]. The difference between distance 12 and distance 16 was not significant [$F(1,6) = 1.49$, MSE = 10,312, ns]. A trend analysis revealed that a linear trend

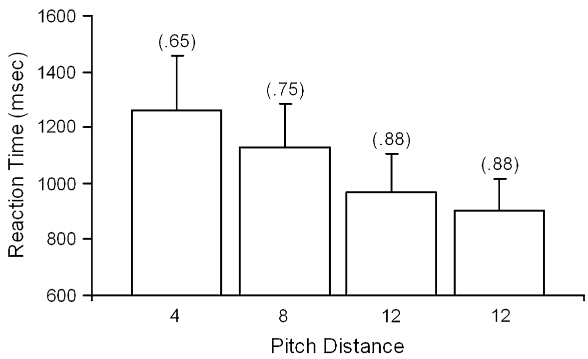

Fig. 3 – RT and accuracy rate (in parentheses) in Experiment 3, as a function of distance. Error bars depict one SEM. Note the different scaling range from Figs. 1 and 2.

explained 97.6% of the variance and gave the best fit [$F(1,6) = 12.53$, MSE = 42,775, $p = .01$] (Fig. 3). As in Experiment 1, and in contrast to Experiment 2, a trend analysis that reflected the two-dimensional representation of music pitch (weights equal −1, 1, −1, 1) explained only 12% of the variance and was not significant [$F(1,6) = 3.19$, MSE = 20,799, ns].

Analysis of the errors revealed a main effect of distance [$F(3,18) = 13.45$, MSE = .006, $p < .001$] (.35, distance 4; .25, distance 8; .12, distance 12; .12, distance 16). Planned comparisons showed that the only significant differences were between distance 4 and distance 8 [$F(1,6) = 10.17$, MSE = .003, $p = .01$], and distance 8 and distance 12 [$F(1,6) = 16.90$, MSE = .003, $p < .01$]. In addition, the correlation between RT and errors was significantly positive [$r(4) = .98$, $p < .05$], thus excluding any RT-accuracy trade-off.

3.3. Discussion

Employing pairs of stimuli with equal gaps and more pairs per condition, produced a linear trend that was similar to Experiment 1 (97.4% in Experiment 1, and 97.6% in Experiment 3). This pattern excludes the possibility that the findings in Experiment 1 were stimuli-specific.

4. General discussion

We studied tonal mental representation with the distance effect. The distance effect has been used previously to investigate the mental representation of other magnitude domains such as numbers. Because the mental representation of music tones has been conceptually linked to two dimensions – pitch and chroma – we hypothesized that comparisons of tones would yield a non-linear pattern of RT. This would be different from representations of other stimuli that are characterized by a single dimension, which varied on a single continuum, such as physical size, luminance, angles, time, or numerical values (Cohen Kadosh and Henik, 2006; Cohen Kadosh et al., 2005; Fias et al., 2003; Ishihara et al., 2008, this issue; Moyer and Landauer, 1967; Restle, 1970). However, in Experiment 1 we found that under a pitch comparison task, the RT pattern yielded a linear distance effect – the larger the pitch distance the faster the RT. This pattern has a surprising similarity to the RT patterns observed in other magnitude tasks. In order to examine whether the observed RT was due to other factors, such as the task employed rather than to the mental representation (Cohen Kadosh et al., 2007d; Tzelgov and Ganor-Stern, 2004), we used a same–different task with the same stimuli. In this task, the RT pattern reflected the two-dimensional representation of music pitch. In Experiment 3 we employed stimuli reflecting a more evenly dispersed selection of music intervals in order to re-assess the findings of Experiment 1. The results of Experiment 3 replicated those of Experiment 1 and demonstrated a linear fit as a function of distance, thus providing evidence that the results obtained in Experiment 1 were not stimuli-specific.

The results of the current study indicate that the distance effect as observed under comparison tasks might not reflect the mental representation of the manipulated features. Rather, it is possible that the similar linear RTs observed for a variety of magnitude comparisons reflect a common mechanism that is affected by stimulus saliency, and which acts according to a similar sensorimotor transformation (Walsh, 2003). Such an explanation is in line with the ATOM framework proposed by Walsh (2003). According to the ATOM, the parietal lobe serves as a common cortical mechanism for time, space, and quantity. It is possible that this mechanism serves any comparison that can be classified as ‘‘more’’ or ‘‘less’’. We would like to emphasize that our results do not indicate that such a common mechanism necessarily means the existence of a common mental representation. It might be that such a mechanism reflects saliency that is expressed in response selection (Cohen Kadosh et al., 2007b), or action planning (Andres et al., 2008, this issue). Indeed, previous studies stressed the importance of the parietal lobe in response selection (Bunge et al., 2002; Cohen Kadosh et al., 2007b, 2007e; Corbetta and Shulman, 2002; Wojciulik and Kanwisher, 1999). Moreover, a previous fMRI study suggested that parietal lobe activation during number processing is at least partly due to response selection demands (Göbel et al., 2004; but see Wood et al., 2006).

Another effect is related to the current discussion – the size congruity effect. When participants are asked to compare two digits that differ in their physical and numerical values, it is hard to focus on one dimension (e.g., physical size) and ignore the other dimension (e.g., the numerical values). Such a situation gives rise to the size congruity effect – participants are slower to respond to incongruent (e.g., 3 5) than to congruent (e.g., 3 5) stimuli (Henik and Tzelgov, 1982). Previous studies suggested that the size congruity can take place at different levels from the representation level or magnitude comparison (Cohen Kadosh and Henik, 2006; Cohen Kadosh et al., 2007b, 2007c, in press-b; Kaufmann et al., 2005; Pinel et al., 2004; Schwarz and Heinze, 1998; Tang et al., 2006; Szucs et al., 2007) up to the response selection (Cohen Kadosh, in press; Cohen Kadosh et al., 2007b; Szucs et al., 2007). The current results support the possibility that the size congruity effect might be due to the fact that both the numerical and size dimensions can be classified similarly (e.g., more/less, larger/smaller) (Cohen Kadosh, in press; Tzelgov et al., 1992). Moreover, Ashkenazi et al. (2008, this issue) reported that a patient with a left IPS lesion revealed a deficient size congruity effect. Our results suggest that such a deficiency might be related to damage to the mechanism involved in processing of magnitude or features that are responsive to comparisons dealing with ‘‘more’’ or ‘‘less’’. Ashkenazi et al.’s (2008, this issue) results also fit the notion that the left IPS is involved in such comparisons.

Note that in the current study we did not employ a within-subject design for differences between comparison task and same–different task across a variety of comparison tasks, in order not to contaminate the data by prior experience and task demands. Therefore, one might suggest that the current results could not be generalized to other domains of magnitudes. Nevertheless, the current study presents a series of results from one domain, music pitch, which provides a unique possibility to examine the distance effect under non-linear mental representation. With these results we demonstrated that the classical distance effect could be observed independent of the mental representation. Therefore, the current results strongly challenge the notion that the distance effect reflects the mental representation of the given dimension.

Alternatively, the results can indicate that in the comparison task, participants focused on one dimension (pitch height) while neglecting another aspect of the mental representation (pitch chroma). This view adds support to the idea that paradigms in which the involvement of intentional strategies is not minimal, can contaminate the processing of the mental entities in question (Cohen Kadosh et al., 2008b; Tzelgov and Ganor-Stern, 2004). This idea also adds to previous evidence that humans generate numerical representations according to task requirements (Fischer and Rottmann, 2005; Shaki and Petrusic, 2005).

Warren et al. (2003) found that the representation of pitch height and pitch chroma is subserved by a separate neuronal substrate in the temporal lobe. However, we speculate that an imaging study employing the pitch comparison task (as in Experiments 1 and 3) would find modulation of parietal activation as a function of distance. Such activation might be observed in the left posterior IPS, similar to what has been observed in a previous study with numbers, physical size, and angles (Fias et al., 2003), or luminance level (Cohen Kadosh et al., 2005). This prediction gains support from the deficient size congruity effect found in a patient with a left IPS lesion reported in this issue (Ashkenazi et al., 2008, this issue). In contrast, we expect that the mental representation for music pitch as revealed by the same–different task would recruit the auditory cortex in the temporal lobe. Similarly, we have recently shown that in a grapheme-color synesthete, changing of task requirements produces a difference in brain areas involved and the time window to observe these activations (Cohen Kadosh et al., 2007d).

An intriguing goal for a further research will be to unearth the development of pitch representation. Such a line of research, together with the current paradigm, can shed light on the long-standing debate whether music is an innate ability or a cultural outcome (for a recent review see Peretz, 2006). In addition, the observance of dissimilarity between the representation of music and other domains supports the idea that some of the components that subserve music might be domain-specific rather than part of a general mechanism (Peretz, 2006; Peretz and Zatorre, 2005).

In sum, our results show that the magnitude comparison task might not be an optimal measurement for mental representation, since it might not reflect the genuine mental representation. This of course does not challenge the idea that numbers are represented linearly, as supported by converging evidence from different experimental paradigms (e.g., Dehaene et al., 1993; Fias and Fischer, 2004; Gevers and Lammertyn, 2005, for SNARC effect; Dehaene and Akhavein, 1995; Verguts and Van Opstal, 2005, for same–different task). Rather, we suggest that other indirect tasks can eliminate any systematic confounding factors related to magnitude processing far more objectively than comparison tasks, thus enabling us to clearly demonstrate the mental representation of music pitch. In addition, we were able to validate, for the first time, the two-dimensional mental representation of tones by using a chronometric approach.

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