The Mental Space of Pitch Height[a]

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ABSTRACT: Through stimulus–response compatibility we tested whether sound frequency (pitch height) elicits a mental spatial representation. Musically untrained and, mostly, trained participants were shown a stimulus–response compatibility effect (Spatial–Musical Association of Response Codes or SMARC effect). When response alternatives were either vertically or horizontally aligned, performance was better when the lower (or leftward) button had to be pressed in response to a low sound and the upper (or rightward) button had to be pressed in response to a high sound, even when pitch height was irrelevant to the task.

KEYWORDS: pitch height; space; SMARC; stimulus-response compatibility

The results are clear-cut and unequivocal. High tones are phenomenologically higher in space than low tones.
C.C. PRATT, 1930

Pratt put forward the hypothesis of pitch–space correspondence after observing that the specific succession of tones in a musical phrase can generate a sensation of apparent movement (e.g., by successively presenting the notes of the diatonic scale from C3 to C4, almost everybody perceives an upward movement). Recent research in human cognition has shown that, in domains such as language and mathematics, discrete sets of unitary elements tend to be unconsciously mapped onto mental spatial positions. Manual key-press responses to large numbers, late months, letters at the end of the alphabet are faster with the right than the left key, whereas responses to small numbers, early months, letters at the beginning of the alphabet are faster with the left than the right key.[1,2] We predicted that, if spatial positions were also spontaneously assigned to the characteristic units of music, a better performance would result when pitch cognitive location corresponded to response location than when it did not. However, the vertical rather than the horizontal dimension could be predominant in the case of pitch

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[a]A more detailed discussion of this study can be found in Rusconi *et al.* Spatial representation of pitch height: the SMARC effect. Cognition. In press (available online at www.sciencedirect.com).

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height, as suggested by its association with the vertical spatial dimension emerging consistently across languages and by early phenomenological reports (e.g., Ref. 3). Specifically, we expected to find responses to high pitches with the upper response key and low pitches with the lower response key (compatible condition) faster and more accurate than responses to high pitches with the lower and to low pitches with the upper response key (incompatible condition).

METHOD

Three experiments were conducted, in which participants (nonmusicians in experiments 1 and 2, and trained musicians in experiment 3) were asked to press one of two keys in response to a target sound. In experiment 1, their task was to determine whether the sound (E3 to G4, except C4) was higher or lower than the reference (C4) and, in experiments 2 and 3, whether the sound (F3 to A4#, except D4) was played by either a wind or a percussion instrument. For each trial participants fixed a cross in the center of a computer screen while the stimuli were presented. In experiment 1, the reference tone was played 1000 ms on each trial immediately before the target tone (lasting 1000 ms too). In experiments 2 and 3 a single tone was played on each trial for 1000 ms. The deadline for a response was fixed at 1300 ms and the intertrial interval at 1000 ms (inclusive of visual feedback on accuracy). Response keys were either horizontally (P and Q on a keyboard) or vertically[b] aligned (spacebar and 6); mappings and responding hands were varied orthogonally within participants (i.e., each possible mapping was performed with both uncrossed and crossed arms in different blocks, and the order of blocks was counterbalanced between participants).

RESULTS

Both latency and accuracy data were analyzed separately for the vertical and the horizontal alignments in each experiment. In experiment 1, two $2 \times 4 \times 2 \times 2$ repeated measures ANOVAs having pitch height (lower/higher), distance from the reference (1, 2, 3, 4 tones), responding hand (left, right) and response location (up/down or left/right) revealed, among the other effects, a significant interaction between pitch height and response location [RTs: $F(1,19) = 7.10$, $P =. 015$; errors: $F(1,19) = 7.10$, $P =. 015$] with vertically aligned response keys. The compatible condition was more accurate and faster than the incompatible condition. Two further ANOVAs on the data with horizontally aligned response keys revealed a marginally significant pitch height × response location interaction in latencies only [RTs: $F(1,19) = 4.19$, $P = .054$; errors: $F < 1$], showing an advantage for right responses to high, and left responses to low pitches. No main effects or interactions involving responding hand were significant.

Data of experiments 2 and 3 were analyzed in $2 \times 2 \times 4 \times 2$ mixed design ANOVAs having musical expertise (no/yes) as a between-participants factor, pitch

[b]In tasks with vertically aligned stimuli, stimulus–response compatibility effects are found irrespective of whether response keys are aligned along the frontal or the transverse plane.[4]

height (lower/higher), distance from the reference (1, 2, 3, 4 tones), and response location (up/down or left/right) as within-participants factors. In the vertical alignment, musical expertise was involved in a significant three-way interaction, with pitch height and response location in the reaction time (RT) analysis [$F(1,38) = 5.616$, P =. 023] and t tests showing that the global compatibility effect was significant for musicians only ($t_{(38)} = 2.66$, $P = .011$; nonmusicians: $t < 1$). However, the compatibility effect was present in either group at a distance of four tones from the implicit reference (D4) [pitch height × distance × response location significant interaction: $F(3,114) = 4.754$, $P = .004$; 4-tone distance: $t_{(38)} = 3.46$, $P = .001$]. The error analysis mirrored the RTs analysis, revealing a pitch height × distance × response location significant interaction (with stimulus–response compatibility at the four-tone distance), whereas musical expertise did not interact with any of the other factors. In the horizontal alignment, musical expertise was involved in a significant four-way interaction with pitch height, distance and response location in the error analysis [$F(3,114) = 3.423$, $P = .020$], which approached significance in the RTs analysis [$F(3,114) = 2.535$, P =. 060]. In both cases the compatibility effect was significant at large distances and for musicians only (errors: four-tone distance, $t_{(38)} = 2.64$, $P = .012$; RTs: three-tone distance, $t_{(38)} = 2.13$, $P = .040$, four-tone distance, $t_{(38)} = 3.07$, $P = .004$).

CONCLUSIONS

Pitch height influenced performance consistently with vertically aligned responses irrespective of its relevance to the task, which suggests that our cognitive system maps pitch onto a mental representation of space. In turn this might shed some light "on the moot question of the apparent auditory movement which is set up by tones of different pitch when presented in succession."[3] We called this phenomenon the SMARC effect, analogous to the SNARC (Spatial-Numerical Association of Response Codes) effect, which was described for numbers.[2] Whether a directional spatial representation is epiphenomenal or plays an equally important role in the development, maintenance, and use of concepts in all these domains of knowledge is still a matter for debate (e.g., Ref. 5) and future investigation.

[Competing interests: The authors declare that they have no competing financial interests.]

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