Cogn Process (2017) 18:75–80
DOI 10.1007/s10339-016-0779-0

SHORT COMMUNICATION

Non-musicians also have a piano in the head: evidence for spatial–musical associations from line bisection tracking

Matthias Hartmann[1]

Received: 19 May 2016 / Accepted: 21 September 2016 / Published online: 30 September 2016

Abstract The spatial representation of ordinal sequences (numbers, time, tones) seems to be a fundamental cognitive property. While an automatic association between horizontal space and pitch height (left-low pitch, right-high pitch) is constantly reported in musicians, the evidence for such an association in non-musicians is mixed. In this study, 20 non-musicians performed a line bisection task while listening to irrelevant high- and low-pitched tones and white noise (control condition). While pitch height had no influence on the final bisection point, participants' movement trajectories showed systematic biases: When approaching the line and touching the line for the first time (initial bisection point), the mouse cursor was directed more rightward for high-pitched tones compared to low-pitched tones and noise. These results show that non-musicians also have a subtle but nevertheless automatic association between pitch height and the horizontal space. This suggests that spatial–musical associations do not necessarily depend on constant sensorimotor experiences (as it is the case for musicians) but rather reflect the seemingly inescapable tendency to represent ordinal information on a horizontal line.

Keywords SMARC (spatial–musical association of response code) · Line bisection · Mouse tracking · SNARC (spatial–numerical association of response code)

Handling editor: Marta Olivetti (Sapienza University of Rome); Reviewers: Tina Weis (University of Kaiserslautern), Yang Seok Cho (Korea University).

✉ Matthias Hartmann
matthias.hartmann@psy.unibe.ch

[1] Department of Psychology, University of Bern, Fabrikstrasse 8, CH-3000, Bern, Switzerland

Introduction

The mental representation of abstract concepts by means of spatial entities is a core property of the human mind and one of the key assumptions of grounded and embodied accounts of cognition (Barsalou 2008; Coello and Fischer 2016; Fischer and Coello 2016). Among the most famous examples is the association between numbers and space, with small numbers represented to the left of larger numbers (the spatial–numerical association of response code; SNARC effect; Dehaene et al. 1993). The dominant view holds that such associations reflect the underlying spatial mental representation of the concepts, such as a "mental number line" (Dehaene et al. 1993; Fischer and Shaki 2014). Crucially, the mental number line can be generalized to other concepts such as letters of the alphabet, days of the week, month of the year (Gevers et al. 2003, 2004), or temporal events ("the mental time line"; cf. Bonato et al. 2012; Hartmann et al. 2014; Ulrich and Maienborn 2010). The origin of these spatial associations is still under debate. On the one hand, adults are constantly confronted with horizontally arranged numbers (e.g., on keypads) and the processing of increasing magnitudes is therefore often linked to a left-to-right sensorimotor experience, which could establish spatial representations (cf. Göbel et al. 2011). On the other hand, spatial representations of ordinal concepts have also been found in newborns (de Hevia et al. 2014) suggesting that there might be an innate tendency to represent ordinal information on a horizontal line (see also Gevers et al. 2003).

An interesting approach to this debate is to look at ordinal concepts that are not constantly accompanied by horizontally arranged symbols and therefore not coupled with a constant left-to-right sensorimotor experience, such as music. Unlike numbers, people typically perceive music without looking at the corresponding visual symbols, and even if this is the case (e.g., when musicians read notes), pitch height is systematically varied in the vertical but not in the horizontal dimension of space (according to common musical notation). Nevertheless, musicians might have explicit sensorimotor experiences with horizontal space and pitch height, for example, when playing piano. Indeed, a spatial–musical association of response code (horizontal SMARC effect, i.e., faster leftward responses to low and faster rightward responses to high tones compared to the opposite mapping) has been found in musicians (Rusconi et al. 2006), and it has been concluded that musicians have a "piano in the head" (Lidji et al. 2007). Whether this association reflects musicians' sensorimotor experience or stimulus–response compatibility effects (or a mixture of both) is still under debate (Cho et al. 2012; Nishimura and Yokosawa 2009; Proctor and Cho 2006; Timmers and Li 2016). Some authors have argued that the horizontal SMARC effect could be a spatial orthogonal stimulus–response compatibility effect (Rusconi et al. 2006; Nishimura and Yokosawa 2009). Accordingly, because high pitch is spatially coded as "up" and a low-pitch tone with "down" (vertical SMARC effect, cf. Rusconi et al. 2006), there is also a low-left and high-right stimulus–response advantage due to orthogonal transformation. If this is true, a horizontal SMARC can also be expected in non-musicians, since non-musicians also show a vertical SMARC effect (Rusconi et al. 2006). However, the current evidence for such an association in non-musicians is mixed. Rusconi et al. (2006) found a trend toward a horizontal association of pitch height, but only when the task required explicit discrimination of pitch height. No spatial association was found when pitch height was task-irrelevant, despite such an association being present in musicians (see also Lidji et al. 2007). In contrast, a horizontal SMARC effect in non-musicians was found in other studies, depending on the timbre and range of the pitch (Weis et al. 2016) or depending on the presence of a reference tone (Cho et al. 2012). These results suggest that a horizontal spatial association of pitch height in non-musicians is not automatic but might be recruited upon specific task demands.

An alternative test for horizontal spatial–musical association outside of classical stimulus–response compatibility settings is the line bisection task. This task is sensitive to attentional asymmetries (i.e., pseudoneglect; Jewell and McCourt 2000) and also to spatially related cues (cf. Calabria and Rossetti 2005; Fischer 2001). Presenting low- and high-pitch tones during line bisection leads to systematic leftward and rightward bisection biases in musicians but not in non-musicians (Lega et al. 2014). In contrast, Ishihara et al. (2013) did find effects of pitch height on line bisection in a population that was not explicitly characterized as musicians. These conflicting results show that the existence of a spatial association of pitch height in non-musicians remains controversial also outside of speeded stimulus–response compatibility settings.

In this study, the horizontal spatial–musical association in non-musicians was further investigated by using a similar line bisection approach than in previous studies (Ishihara et al. 2013; Lega et al. 2014). In contrast to these studies, I will not only analyze a possible bias at the final bisection point, but also during the movement trajectory when approaching the line. The final bisection point is subject to visually guided fine adjustments that might overrule spatial associations of pitch height, whereas movement trajectories might be more sensitive to subtle spatial biases (Haslbeck et al. 2016). Exploring SMARC-like effects in non-musicians with sensitive spatial measurements will provide further insights into the automaticity of spatial association of ordinal information.

Method

Participants

Twenty right-handed participants (mean age 34.7, between 18 and 50 years, 13 women) participated in this study. They gave written informed consent before the experiment, which was approved by the Ethics Committee of the University of Bern. All participants reported that they do not play (or have not played) an instrument (or vocal training) and were therefore classified as non-musicians.

Stimuli and procedure

Low (110 Hz) and high (1760 Hz) sinusoidal sound stimuli, as well as white-noise sound stimuli, were created with Audacity (http://audacity.sourceforge.net). Sound stimuli were matched for subjective loudness in a pretest ($n = 5$). This was important because loud stimuli tend to be associated with the right side of space (Chang and Cho 2015; Hartmann and Mast 2016). Black lines appeared in the upper half of a white screen on a MacBook Pro (1024 × 768 pixels), 250 pixels above the screen center. The thickness of the lines was set to 15 pixels, while their length (650, 750, or 850 pixels) and horizontal position (central, ±50, and ±100 pixels) varied, resulting in 15 unique lines. All 15 lines were paired with high, low, and white-noise stimuli, presented via headphones, and the resulting 45 trials were presented in random order. Five practice trials preceded the 45 experimental trials.

Participants were seated about 60 cm in front of the screen and instructed to click with the mouse cursor (that had the shape of a cross) as precisely as possible at the center of the line. Each trial started with a black dot (30 × 30 pixels) appearing at the bottom of the screen (300 pixels below the screen center). Participants were required to click at this dot, which triggered the onset of the line and sound stimulus (see Fig. 1). The horizontal position of the dot corresponded to the center of the line. Thus, the moving distance toward the line was constant in all trials, and participants needed to move the cursor in a straight vertical line upward across the screen. Note that in classical mouse-tracking studies, participants moved the cursor from a central bottom position toward a leftward or rightward top position (Freeman et al. 2011; Spivey et al. 2005). In the present study, I wanted to avoid such curved trajectories since the salient leftward and rightward drifts might potentially influence the line bisection performance (Brodie and Pettigrew 1996) and overrule subtle influences of the tonal cues. With the setting of the present study, horizontal deviations in cursor movements can be attributed to influences of the tonal cues instead of task-specific requirements.

After the onset of the line and sound, participants had 6 s to perform the bisection. If they did not respond within 6 s, the line disappeared and the message "please respond faster" appeared on the screen and the trial was repeated. This time constraint was implemented to keep trial durations in a similar range across conditions and participants.

Stimulus presentation and data recording were controlled by PsychoPy (Peirce 2007). A standard USB mouse was used. The mouse movement speed was set to level 2 (out of 10) in the control panel, resulting in cursor displacement on the screen of about 80 pixels per cm of mouse/hand movement (cf. Fischer and Hartmann 2014). Mouse cursor positions were recorded at 50 Hz.

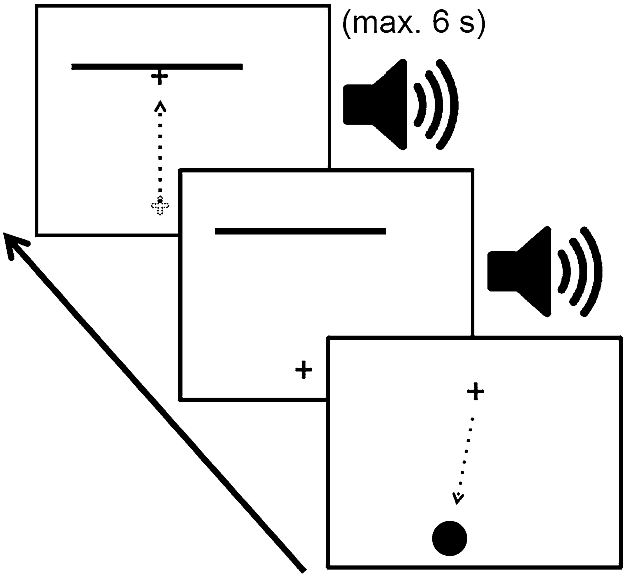

Fig. 1 Sequence of a trial. Participants click on the *dot* at the *bottom*. This action triggers the onset of the sound and the line. Participants then move the cursor up toward the line and confirm their final bisection point by mouse click within 6 s

Data analysis

We compared the deviation of the correct line center (in pixels, negative values represent leftward deviations) for the three different sound conditions with regard to the time point, where the mouse cursor initially approached the line before perceptually guided fine adjustments were performed, and with regard to the final bisection point (by mouse click). For each participant, the median deviation of the 15 trials per sound condition was computed and transmitted to a repeated measures analysis of variance (ANOVA) with the variable sound condition (high pitch, low pitch, and white noise). In addition, we compared the movement trajectory from the bottom starting point toward the line in the top of the screen for the three sound conditions. To this end, x and y cursor coordinates were time-normalized to 100 data points and the horizontal position of the three sound conditions were tested against each other by paired t tests for each data point. Differences were considered as significant when the p value of at least five successive data points was below .05 (cf. Hartmann et al. 2015).

Results

Five trials (from five different participants) needed to be repeated due to slow responses (>6 s). Participants bisected the line on average 2.22 s after the onset of the line, and there was no difference for the initial and final bisection time between the three sound conditions ($ps > .05$).

The ANOVA on the initial bisection point revealed a significant main effect of sound condition, $F(2, 38) = 5.02$, $p = .012$, $\eta_p^2 = .21$. Pairwise comparison revealed that lines were initially bisected significantly more rightward in the high-tone condition compared to the low-tone and white-noise condition ($ps < .05$; Bonferroni–Holm corrected). In contrast, the ANOVA on the final bisection point revealed no significant effect of sound condition, $F(2, 38) = 1.44$, $p = .249$, $\eta_p^2 = .07$ (see Fig. 2).

Notably, when tested against zero (true line center), only the initial bisection point in the high-tone condition showed a significant deviation ($p = .031$). Thus, a general leftward bias ("pseudoneglect") that is usually found in healthy participants' line bisection performance (Jewell and McCourt 2000) was absent in this study, but this is not an unusual finding (e.g., Darling et al. 2012).

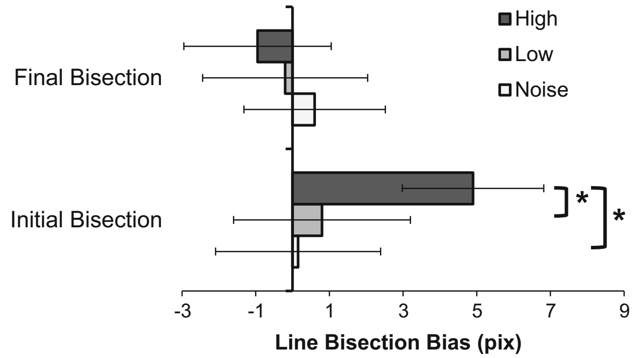

Fig. 2 Mean deviations from the line center of the initial and final bisection estimation for the three sound conditions. *Asterisks* represent significant differences (*$p < .05$). *Error bars* depict ± 1 *SEM*

In order to assess how the spatial bias for the initial bisection point emerged, the mean x and y coordinates for the 100 normalized time points were plotted for each sound condition (Fig. 3). For this plot and the following analyses, trials with a maximum horizontal deviation from the center of the line of more than 2.5 standard deviations from the individual mean were excluded (4.97 % of trials). Figure 3 shows that there is an initial leftward drift in the low-pitched condition. Between the 37th and 43rd data point (from bottom to top), the horizontal position in the low-pitched condition was significantly more leftward when compared to the white-noise condition ($p < .05$ for seven consecutive data points), but the difference between the low- and high-tone condition was not significant. Remarkably, in the first half of the movement, there was a general rightward drift in all three sound conditions. This might be due to the initiation of a right-handed movement (cf. Haslbeck et al. 2016). Interestingly, at the end of the movement when approaching the line, this rightward drift changed into a leftward drift back to the line center, with the exception of the high-tone condition that drifted even more rightward. For the last five data points before the cursor hit the line (initial bisection point), the mouse cursor was significantly more rightward in the high-pitch condition compared to the low-pitch and white-noise condition (all $ps < .05$).

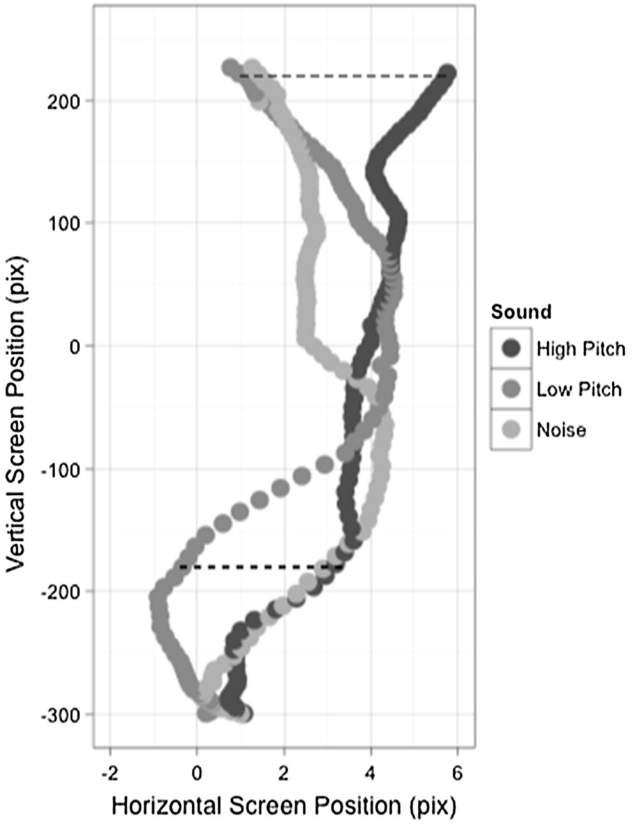

Fig. 3 Horizontal and vertical mouse cursor positions of the time-normalized data. *Dotted horizontal line* in the *lower part* indicates significant differences between the low-pitch and white-noise condition, and the *dotted horizontal line* in the *upper part* indicates significant differences between the high-pitch and low-pitch/noise condition ($p < .05$ for five consecutive data points)

Discussion

The aim of this study was to assess horizontal spatial–musical associations in non-musicians. It was found that task-irrelevant tones biased line bisection performance: Lines were initially bisected more rightward when perceiving a high compared to low-pitched tone or noise. This finding provides evidence for an automatic horizontal spatial–musical association in non-musicians. Most previous studies did not find such an association when pitch was task-irrelevant (Fischer et al. 2013; Lega et al. 2014; Lidji et al. 2007; Pitteri et al. 2015; Rusconi et al. 2006; Stewart et al. 2013; but see Cho et al. 2012; Weis et al. 2016), and it was concluded that only musicians have inherent horizontal musical–spatial associations, due to their specific history of action–effect coupling (cf. Stewart et al. 2013). The results from this study suggest that non-musicians also have "a piano in the head," but the horizontal spatial–musical associations are only subtle and may only be revealed by a sensitive and dynamic measurement of spatial biases, such as mouse tracking during line bisection (see also Haslbeck et al. 2016). In fact, the analysis of the time course of spatial biases showed that the relative rightward drift in the high-tone condition manifested itself just before reaching the line, suggesting that pitch height modulated the visuomotor interplay when approaching the stimulus (cf. Rinaldi et al. 2016). It is likely that in this final phase of approaching the target, approximate mid-point estimation is performed, which is influenced by the spatial–musical association. Particularly, pitch height might have influenced attentional processing due to its underlying spatial representation, such as an enhanced visual processing of the right side of the line in the high-pitch condition, resulting in a rightward bias in initial line bisection. However, in line with previous studies, there was no effect of pitch height for the final bisection estimation (Lega et al. 2014). Thus, the visually guided fine adjustments that were performed for the final bisection point overruled the effect of pitch height, suggesting that pitch height did not change the perception of visual stimuli, but rather how stimuli are preprocessed (i.e., approximate midpoint estimation) and approached.

Importantly, the difference in movement trajectory between the low- and high-pitch tones was significant only just before reaching the task-relevant stimulus (i.e., the horizontal line). This suggests that pitch height interacted with the spatial (pre)processing of the critical stimulus, rather than with the motor execution of the straight-ahead movement alone (in the latter case, the effect would be independent of the bisection task). However, it is unclear why there was a leftward bias in the low-pitched condition (vs. baseline) in the early phase of the motion trajectory and a rightward bias in the high-pitched condition (vs. baseline) in the final part of the motion trajectory. Future studies could explore the temporal dynamics of spatial–musical associations more explicitly.

Importantly, the fact that a horizontal spatial association is also present in non-musicians questions the necessity of sensorimotor experiences for the establishment of mental spatial associations, which is assumed in strong views of embodied cognition (Barsalou 2008). Notably, non-musicians may not be lacking sensorimotor experiences between the horizontal space and pitch height completely: It is likely that most adults have played the piano once in their lifetime and have seen written notes with ascending pitch from left to right, for example, when learning musical notations in school. It can therefore not be ruled out that sensorimotor experiences contributed to the effect found in this study (for a similar discussion, see Nishimura and Yokosawa 2009). Nevertheless, it can be concluded that constant sensorimotor experiences are not mandatory for the establishment of spatial associations of abstract concepts.

The emergence of associations (e.g., between response side and stimulus attributes) without extensive learning is often explained by polarity correspondence (Proctor and Cho 2006). According to this account, stimulus and response dimensions are mapped along a positive and negative polarity. For example, left and low-pitched tones are attributed to the negative pole and right and high-pitched tone to the positive pole, which might lead to congruity effects when the polarity dimensions correspond (Cho et al. 2012; Nishimura and Yokosawa 2009; Rusconi et al. 2006). The polarity correspondence account has been put forward in the context of speeded binary classification tasks (Proctor and Cho 2006), and previous studies showed that polarity correspondence contributes to the SMARC effect (Cho et al. 2012). Although no binary response was required in this study, it is still conceivable that the spatial (left, right) and musical (low, high) dimensions were processed with similar entities and that correspondence between these entities systematically affected sensorimotor behavior. While the exact mechanisms for spatial–musical associations still remain unclear, this study showed—using a sensitive spatial measurement—that extensive sensorimotor experience between pitch height and space is not necessary for SMARC-like effects. Rather, it seems that there is an inescapable tendency to mentally arrange ordinal information along a horizontal line.

References

Barsalou LW (2008) Grounded cognition. Annu Rev Psychol 59:617–645. doi:10.1146/annurev.psych.59.103006.093639

Bonato M, Zorzi M, Umilta C (2012) When time is space: evidence for a mental time line. Neurosci Biobehav Rev 36(10):2257–2273. doi:10.1016/j.neubiorev.2012.08.007

Brodie EE, Pettigrew LEL (1996) Is left always right? Directional deviations in visual line bisection as a function of hand and initial scanning direction. Neuropsychologia 34(5):467–470

Calabria M, Rossetti Y (2005) Interference between number processing and line bisection: a methodology. Neuropsychologia 43(5):779–783. doi:10.1016/j.neuropsychologia.2004.06.027

Chang S, Cho YS (2015) Polarity correspondence effect between loudness and lateralized response set. Front Psychol 6:683

Cho YS, Bae GY, Proctor RW (2012) Referential coding contributes to the horizontal SMARC effect. J Exp Psychol Hum Percept Perform 38:726–734

Coello Y, Fischer MH (2016) Foundations of embodied cognition—Volume 1. Perceptual and emotional embodiment. Taylor & Francis, London

Darling S, Logie RH, Della Sala S (2012) Representational pseudoneglect in line bisection. Psychon Bull Rev 19(5):879–883

de Hevia MD, Izard V, Coubart A, Spelke ES, Streri A (2014) Representations of space, time, and number in neonates. Proc Natl Acad Sci 111(13):4809–4813

Dehaene S, Bossini S, Giraux P (1993) The mental representation of parity and number magnitude. J Exp Psychol Gen 122(3):371–396

Fischer MH (2001) Number processing induces spatial performance biases. Neurology 57(5):822–826

Fischer MH, Coello Y (2016) Foundations of embodied cognition—Volume 2: conceptual and interactive embodiment. Taylor & Francis, London

Fischer MH, Hartmann M (2014) Pushing forward in embodied cognition: may we mouse the mathematical mind? Front Psychol 5:1–4. doi:10.3389/fpsyg.2014.01315

Fischer MH, Shaki S (2014) Spatial associations in numerical cognition—from single digits to arithmetic. Q J Exp Psychol (Hove) 67(8):1461–1483. doi:10.1080/17470218.2014.927515

Fischer MH, Riello M, Giordano BL, Rusconi E (2013) Singing numbers… in cognitive space—a dual-task study of the link between pitch, space, and numbers. Top Cognit Sci 5:354–366

Freeman J, Dale R, Farmer T (2011) Hand in motion reveals mind in motion. Front Psychol 2:59

Gevers W, Reynvoet B, Fias W (2003) The mental representation of ordinal sequences is spatially organized. Cognition 87(3):B87–B95. doi:10.1016/S0010-0277(02)00234-2

Gevers W, Reynvoet B, Fias W (2004) The mental representation of ordinal sequences is spatially organised: evidence from days of the week. Cortex 40(1):171–172

Göbel SM, Shaki S, Fischer MH (2011) The cultural number line: a review of cultural and linguistic influences on the development of number processing. J Cross Cult Psychol 42(4):543–565

Hartmann M, Mast FW (2016) Loudness counts: interactions between loudness, number magnitude and space. Q J Exp Psychol. doi:10.1080/17470218.2016.1182194

Hartmann M, Martarelli CS, Mast FW, Stocker K (2014) Eye movements during mental time travel follow a diagonal line. Conscious Cogn 30C:201–209. doi:10.1016/j.concog.2014.09.007

Hartmann M, Mast FW, Fischer MH (2015) Spatial biases during mental arithmetic: evidence from eye movements on a blank screen. Front Psychol 6:12. doi:10.3389/fpsyg.2015.00012

Haslbeck JM, Wood G, Witte M (2016) Temporal dynamics of number-space interaction in line bisection: comment on Cleland and Bull (2015). Q J Exp Psychol 69(6):1239–1242

Ishihara M, Revol P, Jacquin-Courtois S, Mayet R, Rode G, Boisson D, Rossetti Y (2013) Tonal cues modulate line bisection performance: preliminary evidence for a new rehabilitation prospect. Front Psychol 4:704

Jewell G, McCourt ME (2000) Pseudoneglect: a review and meta-analysis of performance factors in line bisection tasks. Neuropsychologia 38(1):93–110

Lega C, Cattaneo Z, Merabet LB, Vecchi T, Cucchi S (2014) The effect of musical expertise on the representation of space. Front Hum Neurosci 8:1–9. doi:10.3389/fnhum.2014.00250

Lidji P, Kolinsky R, Lochy A, Morais J (2007) Spatial associations for musical stimuli: a piano in the head? J Exp Psychol Hum Percept Perform 33(5):1189–1207. doi:10.1037/0096-1523.33.5.1189

Nishimura A, Yokosawa K (2009) Effects of laterality and pitch height of an auditory accessory stimulus on horizontal response selection: The Simon effect and the SMARC effect. Psychon Bull Rev 16(4):666–670

Peirce JW (2007) PsychoPy—psychophysics software in Python. J Neurosci Methods 162(1):8–13

Pitteri M, Marchetti M, Priftis K, Grassi M (2015) Naturally together: pitch-height and brightness as coupled factors for eliciting the SMARC effect in non-musicians. Psychol Res. doi:10.1007/s00426-015-0713-6

Proctor RW, Cho YS (2006) Polarity correspondence: a general principle for performance of speeded binary classification tasks. Psychol Bull 132:416–442

Rinaldi L, Lega C, Cattaneo Z, Girelli L, Bernardi NF (2016) Grasping the sound: auditory pitch influences size processing in motor planning. J Exp Psychol Hum Percept Perform 42(1):11–22. doi:10.1037/xhp0000120

Rusconi E, Kwan B, Giordano BL, Umilta C, Butterworth B (2006) Spatial representation of pitch height: the SMARC effect. Cognition 99(2):113–129. doi:10.1016/j.cognition.2005.01.004

Spivey MJ, Grosjean M, Knoblich G (2005) Continuous attraction toward phonological competitors. Proc Natl Acad Sci USA 102(29):10393–10398

Stewart L, Verdonschot RG, Nasralla P, Lanipekun J (2013) Action–perception coupling in pianists: learned mappings or spatial musical association of response codes (SMARC) effect? Q J Exp Psychol 66(1):37–50

Timmers R, Li S (2016) Representation of pitch in horizontal space and its dependence on musical and instrumental experience. Psychomusicol: Music Mind Brain 26:139–148

Ulrich R, Maienborn C (2010) Left-right coding of past and future in language: the mental timeline during sentence processing. Cognition 117(2):126–138. doi:10.1016/j.cognition.2010.08.001

Weis T, Estner B, Lachmann T (2016) When speech enhances spatial musical association of response codes: joint spatial associations of pitch and timbre in nonmusicians. Q J Exp Psychol 69:1687–1700