Implicit chord processing and motor representation in pianists

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Abstract

The aim of this paper is to assess the relevance of pitch dimension in auditory-motor interaction. Several behavioral and brain imaging studies have shown that auditory processing of sounds can activate motor representations, an effect which is however elicited only by action-related sounds, i.e., sounds linked to a specific motor repertoire. Music provides an appropriate framework for further exploration of this issue. Three groups of participants (pianists, non-pianist musicians and non-musicians) were tested with a shape decision task where left-hand and right-hand responses were required; each visual stimulus was paired with an auditory task-irrelevant stimulus (high-pitched or low-pitched piano-timbre chords). Of the three groups, only pianists had longer reaction times for left-hand/high-pitched chords and right-hand/low-pitched chords associations. These findings are consistent with an auditory-motor effect elicited by pitch dimension, as only pianists show an interaction between motor responses and implicit pitch processing. This interaction is consistent with the canonical mapping of hand gestures and pitch dimension on the piano keyboard. The results are discussed within the ideo-motor theoretical framework offered by the Theory of Event Coding (Hommel et al., 2001. Behavioral and Brain Sciences, 24, 849–937).

Keywords: music, auditory-motor interaction, pitch

Performing music requires close interplay between the auditory and the motor systems (Pfordresher 2006). When a musician performs an action on his instrument, by moving his fingers over a piano keyboard for example, an effect is produced (in this case, piano sounds); his ultimate aim in performing the action is to exploit the action-effect relationship to produce melodies and chords. This study focuses on this relationship in pianists.

The nature of the relationship between actions and action effects at a representational level was conceptualized by Hommel and colleagues (2001) in a theoretical framework defined as the Theory of Event Coding (TEC). The core contention of this hypothesis is that "codes of perceived events (e.g. action effect) and planned actions share a common representational domain, to the effect that perceptual codes and action codes may prime each other on the basis of their overlap in this domain" (Hommel et al., 2001, p. 850). The concept of "common representational domain", or "common code" (see also Prinz, 1997; Hommel, 2009), plays a key role in the ideo-motor principle at the basis of the TEC; the anticipation of a goal, in terms of action effects, helps to select and plan a voluntary action. A specific brain basis has been proposed for this ideo-motor principle (Melcher et al. 2008). The emergence of an integration between perceptual codes (action effects) and action codes (motor representations) at the level of a common representational domain, an essential process for a voluntary control of actions, is an acquired phenomenon resulting from repeated and contingent action-effect experiences (Elsner & Hommel, 2001).

According to TEC, stimuli experienced as action effects may thereafter activate the associated action (see Hommel, 2009 for a review). Several studies suggest that this is the case, in terms of auditory-motor interactions (Zatorre et al. 2007), for musicians during music processing (Drost et al. 2005a; Drost et al. 2005b; Drost et al.

2007; Keller and Koch 2006a, 2006b, 2008). Drost and co-workers (2005a) found that action representations are activated in pianists when they perceive piano chords. Their participants (pianists vs. non-musicians) were required to play chords on a piano keyboard in response to visual stimuli. Auditory task-irrelevant stimuli, congruent or incongruent with action effects (e.g., a C major chord visual stimulus coupled with a C major or a C minor chord auditory stimulus), were presented concurrently. The results showed that only the pianists had slower response times when the auditory stimuli were incongruent with the required response. In a more recent study, Drost and colleagues (2007) obtained complementary results to those obtained in their previous study. The task used was similar to the earlier task, but the auditory stimuli were presented as five different timbres; pianists had slower RTs only for incongruent conditions with piano or organ timbres and guitarists only for guitar timbres (guitar fingerboards were used as a response device). This clearly suggests that, for musicians only, action representations are activated when musical sounds (action effects) are processed and more specifically, this effect emerges when musicians process sounds generated by their own instrument. A magnetoencephalography (MEG) study conducted by Haueisen and Knosche (2001) provided neurophysiological corroboration. In their study, pianists listening to piano music exhibited involuntary motor activity involving the contra-lateral primary motor cortex (M1), an effect which was absent in non-pianist musicians. Similar results were obtained in a TMS experiment by D’Ausilio and colleagues (2006). Moreover, it has been proposed that the insular cortex may play a role in the initial phase of the action-perception association (Mutschler et al 2007). The results obtained by Drost were integrated by those of Keller and Koch (2006a; 2006b; 2008) who found that not only perception, but also action-effect anticipation plays a role in planning and executing sequential movements triggering music-like sounds.

The studies described above indicate that music processing does have an effect on motor performance and activates motor-related brain circuits, but the issue of which sound characteristics actually trigger the motor effect has not been adequately studied. The objective of the present research is to investigate, by means of a behavioural experiment, whether the pitch dimension plays a role in the emergence of an auditory-motor interaction effect, an hypothesis which has not been explicitly addressed by previous studies.

It has been proposed that pitch has a complex helix-shaped representation onto which two dimensions are mapped: pitch chroma, mapped onto the spiral plane, and pitch height, mapped onto the linear plane (Shepard 1982; Ueda and Ohgushi, 1987). Pitch chroma refers to a categorical property of sounds (e.g., all the C notes on a C major scale), while pitch height refers to the perceived fundamental frequency of a sound (each individual note of a musical scale has a specific frequency). This study specifically addresses the pitch-height dimension.

Previous research on mental representation of pitch-height dimension in musicians suggests that the “cognitive system maps pitch onto a mental representation of space” (Rusconi et al., 2006, p. 126). In fact, when performing a timber identification task of sounds with different pitches, musicians are faster on low-pitched tones when pressing a left-side key and on high-pitched tones when pressing a right-side key (Rusconi et al. 2006; Lidji et al., 2007). This phenomenon has been called the Spatial Musical Association of Response Code (SMARC) effect. As we will demonstrate later, the SMARC effect could be involved in our experiment, leading to specific predictions.

The three groups (pianists, non-pianist musicians and non-musicians) of participants in our experiment were asked to decide whether a visual stimulus was a circle or a rectangle, and then to communicate their decision by pressing a key to their right or left with their right or left index finger. A task-irrelevant auditory stimulus (a high- or low-pitched chord with a piano timbre) was associated with each visual stimulus. The TEC allows us to advance specific predictions regarding the results. A common code for action and action effects, in consequence of previous piano playing, should lead to an association between right-hand and high-pitched sounds and left-hand and low-pitched sounds, but only in pianists. The structural organization of a piano keyboard imposes a specific mapping between hand actions and sound pitch. High-pitched sounds are located on the right side of the keyboard and low-pitched on the left. This distribution leads to a specific action-effect and, according to the TEC model, to a representation that links action (the movement of the fingers of the right or left hand over a piano keyboard) and action effects (the pitch of the sound produced). As this association is bidirectional, the sound (action effect) processing should activate the representation of an action that usually leads to its production, so that high-pitched chords should prime right-hand responses, and low-pitched chords left-hand responses. A slightly different prediction can be made, based on the SMARC effect. As said before, when performing a timber identification task of sounds with different pitches, musicians are faster on low-pitched tones when pressing a key to their left and on high-pitched tones when pressing a key to their right (Rusconi et al. 2006; Lidji et al., 2007). If this is true, in our experiment both pianists and non-pianist musicians should show association between right-hand responses and high-pitched sounds and left-hand responses and low-pitched sounds.

We also introduced the distinction between global and local pitch-height effects (see figure 1); this was introduced to test whether a possible relationship between hand response and pitch height is simply dichotomously distributed following a left-right contrast or if there is also a linear distribution along a continuous gradient. A global pitch effect would imply facilitation of the left-hand responses for all the low-pitched chords and of the right-hand responses for all the high-pitched chords included in the task. A local pitch effect, which assumes the presence of a global pitch effect, would imply the presence of a facilitation gradient, thus the higher the pitch the greater the facilitation for the right-hand responses, and the lower the pitch the greater the facilitation for the left-hand responses.

EXPERIMENT

Method

Participants

Three groups of participants took part in the Experiment: fourteen right-handed pianists (6 females and 8 males; average age: 23.4 years); 14 right-handed non-pianist musicians (6 females and 8 males; average age: 26.1 years); 14 right-handed non-musicians (10 females and 4 males; average age: 24 years).

The musicians were post-graduate music students from the Giuseppe Verdi Conservatory, Milan, and the Giuseppe Tartini Conservatory, Trieste. Pianists and non-pianist musicians had, on average, 14.3 and 13.6 years of musical training respectively. The group of non-pianist musicians was composed of 6 guitarists, 4 percussionists, one violinist, one flautist, one clarinet player and one singer. The non-musicians were undergraduate students from the University of Milano-Bicocca, none of whom had ever played a musical instrument. All participants gave written informed consent.

Materials

The experiment was conducted in a dimly lit, soundproofed room. Participants were seated at approximately 60 cm from a 15.4’’computer screen. Presentation of stimuli and registration of Reaction Times (RTs) were controlled using the E-Prime software (version 1.2, Psychological Tools, Inc). The visual stimuli used were a black cross (which served as a central fixation point) and two green geometric shapes (a 5° x 2.5° rectangle and a circle with a diameter of 3.4°), projected on the centre of the screen on white background. The auditory stimuli (see Figure 1) were composed of two major triads, C major and F major, varying along the high-pitch/low-pitch dimension, so that in terms of global pitch there were two high-pitched triads (C4-E4-G4 and F4-A4-C5) and two low-pitched triads (C1-E1-G1 and F1-A1-C2), and in terms of local pitch there were two extreme triads (C1-E1-G1 and F4-A4-C5) and two medium triads (F1-A1-C2 and C4-E4-G4). Each chord was recorded from an acoustic piano and the audio signal was normalized at 75% using Adobe Audition software and played at approximately 65 dB SPL through professional headphones. Participants responded by pressing the F1 or the F12 key on a computer keyboard with either their left or right index finger.

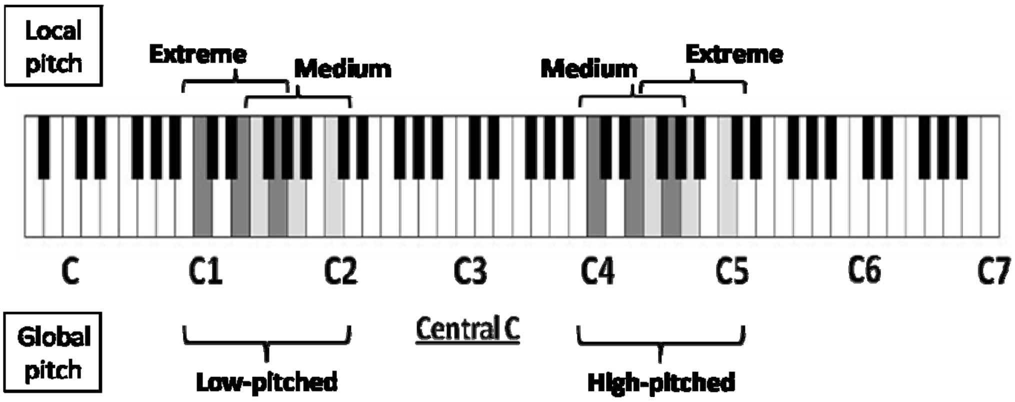


Figure 1: Distribution of the auditory stimuli along the piano keyboard. Dark-grey = C major chords; Light-grey = F major chords; C1, C2, ... = C keys

Procedure and design

The examiner described the task to the participants and explained that the sound stimuli were intended to distract their attention from the visual task, that they were not informative and were to be completely ignored. Each trial started with a 500 ms presentation of the fixation point, followed by the high-pitched or low-pitched chord, the maximum duration of which was 700 ms. The visual stimulus was projected 100 ms after the auditory stimulus and overlapped it until the participant communicated his/her decision regarding the shape (rectangle or circle) of the visual stimulus by pressing either the left or the right key (F1 or F12) on the computer keyboard, within the 1000 ms time limit. The introduction of the 100 ms asynchrony between auditory and visual stimuli is assumed to align the beginning of the visuo-motor task with a complete higher-order spectral sound analysis (Shanin et al. 2003). For 50% of the participants the left-hand response corresponded to the rectangle and the right-hand response to the circle, and conversely for the remaining 50%. This procedure was adopted to prevent interference caused by the remapping of figure-key assignment during the experiment (see Mapelli et al. 2003 and Gevers et al. 2006 for a similar procedure).

The experiment was structured as follows: a training block of 20 trials, followed by 3 blocks (80 trials per block), each consisting of a random combination of the two visual and the four auditory stimuli, with a short interval between blocks, the duration of which was decided by the participant. The whole experiment lasted about 20 min.

Data analysis

Only RTs on correct responses were analysed. Responses with particularly long latencies (defined as two SDs or more from the mean reaction time for each participant and condition) or faster than 200 ms, were excluded from the analysis.

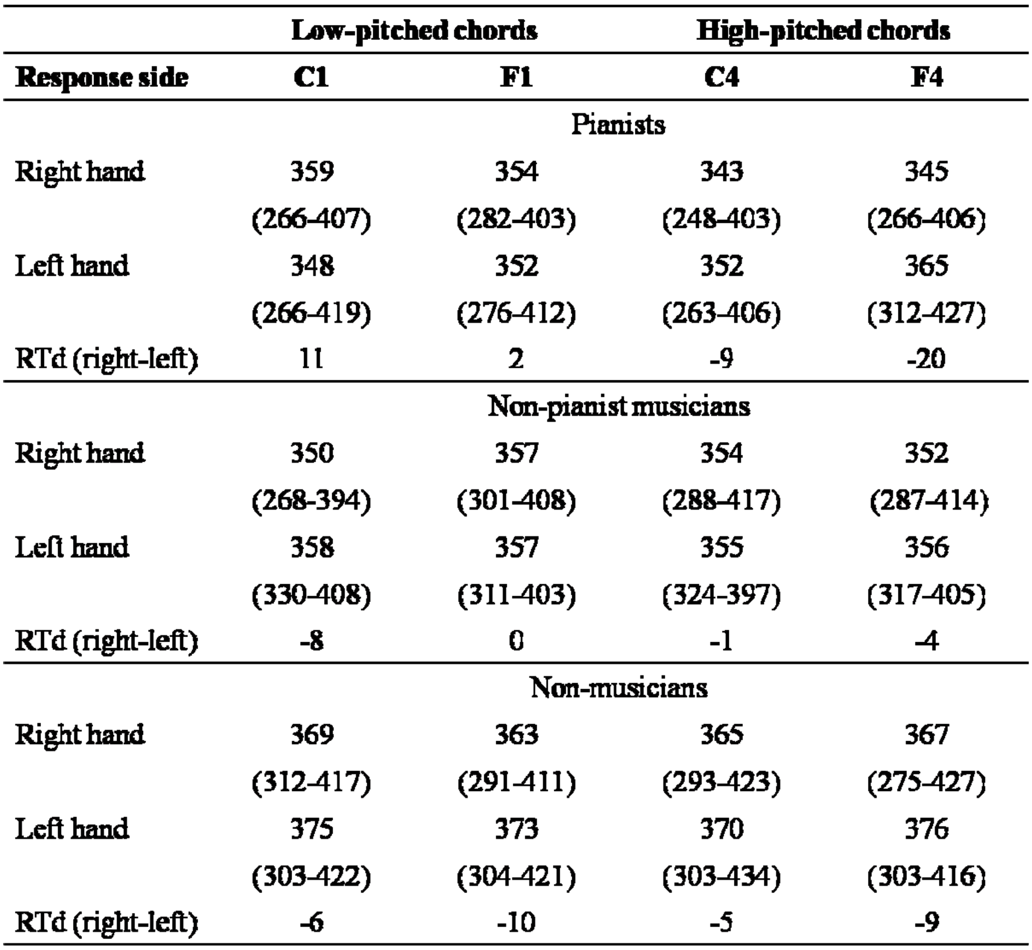
Statistical analyses were performed on the median RT differences (RTd) between the responses of the right hand and left hand for all conditions in order to investigate the relationship between chord pitch and response side. If left hand responses are faster for low-pitched chords, the right-minus-left difference will be positive; on the contrary, if right hand responses are faster for high-pitched chords, the difference will be negative. In an ANOVA analysis, a relationship between hand response and chord pitch will thus emerge as a main effect rather than a response hand by pitch height interaction (see Lidji et al. 2007 for a similar procedure). In fact, the use of right–minus-left differences instead of simple median RTs merely modifies the level at which the relationship emerges with no effect on the variables included in the statistical model (see note 1 in the Results section).

Data were analyzed with two different procedures: a repeated measure ANOVA and a regression analysis. The ANOVA was performed to study the interactions among variables. The regression analysis (Lorch & Meyers, 1990) evaluates the linear relation between the target variable (chord pitch) and the RTd for each participant, hence avoiding a potential overestimation of the effect due to group averaging. The emergence of a negative slope, whose regression weight is significantly different from 0 in a single sample t-test, would suggest a relationship between low-pitched chords and left-hand responses and high-pitched chords and right-hand responses (Lidji et al. 2007). The regression analysis was performed using the logarithm of the first note pitch-frequency of each chord as predictor. The logarithmic scale is widely used in music research because it has been demonstrated that the human perceptual system perceives pitch according to this nonlinear scale (Shepard, 1982). We borrowed this analysis procedure from the Spatial Numerical Association of Response Code (SNARC) effect literature, in which it is frequently used to study the association between response side and number magnitude (Fias et al. 1996).

Converging results from the ANOVA and Regression analyses will confirm the validity of the results.

Results

The participants made very few errors (less than 5%), so no data analysis was performed on error rates. The percentage of trials discarded because of errors or RT cut-offs was as follows: 4.9 % for pianists, 2.4% for non-pianist musicians and 3.6% for non-musicians. The lack of RTs and error rate correlation computed using the grand average values (r = 0.119, n.s.) indicated that there was no speed-accuracy trade-off. Table 1 displays the averaged median RTs for the right-hand and left-hand responses as a function of the chord pitch.



	Low-pitched chords		**High-pitched chords**	
Response side	**C1**	**F1**	**C4**	**F4**
		Pianists		
Right hand	359 (266-407)	354 (282-403)	343 (248-403)	345 (266-406)
Left hand	348 (266-419)	352 (276-412)	352 (263-406)	365 (312-427)
RTd (right-left)	11	2	-9	-20
		Non-pianist musicians		
Right hand	350 (268-394)	357 (301-408)	354 (288-417)	352 (287-414)
Left hand	358 (330-408)	357 (311-403)	355 (324-397)	356 (317-405)
RTd (right-left)	-8	0	-1	-4
		Non-musicians		
Right hand	369 (312-417)	363 (291-411)	365 (293-423)	367 (275-427)
Left hand	375 (303-422)	373 (304-421)	370 (303-434)	376 (303-416)
RTd (right-left)	-6	-10	-5	-9

Table 1: Average Median RTs and ranges, in brackets, for the shape decision task in milliseconds and differences between right-hand and left-hand responses (RTd) for each group as a function of the chord height (C = C major chord; F = F major chord, see figure 1).

RTd were analyzed by means of a three-way ANOVA. *Global pitch* (high or low-pitched chords) and *Local pitch* (relative pitch within categories) were the within-subject variables; participant groups (pianists, non-pianists musicians and non-musicians) were the between-subject variable.

The analysis identified a main effect of Global pitch [F(1, 39) = 5.91, MSE = 301.05, p = .02] indicating that participants had shorter RTs on the left hand than on the right hand to low-pitched chords, and shorter RTs on the right hand than on the left hand to high-pitched chords. The significant interaction between Global pitch and Group indicated that the Global pitch effect was different in the three groups of participants [F(2, 39) = 7.76, MSE = 301.05, p = 0.001]. Post-hoc comparisons, computed using the Bonferroni t-test, indicate that the Global pitch effect appears in pianists only (Pianists vs Non-pianist musicians and Pianists vs Non-musicians, p = 0.0001; see Figure 2). In fact, only pianists obtained positive RTd for low-pitched chords and negative RTd for high-pitched chords (see Table 1). No other effects emerged from the ANOVA[1].

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[1] Comparable results were obtained using mean RTs instead of difference scores (RTd) and applying a four-way mixed ANOVA - with response hand (right vs left), global pitch (high-pitched vs low-pitched), local pitch (extreme vs medium) and group (pianists vs non-pianist musicians vs non-musicians) as factors - instead of a three-way mixed ANOVA.

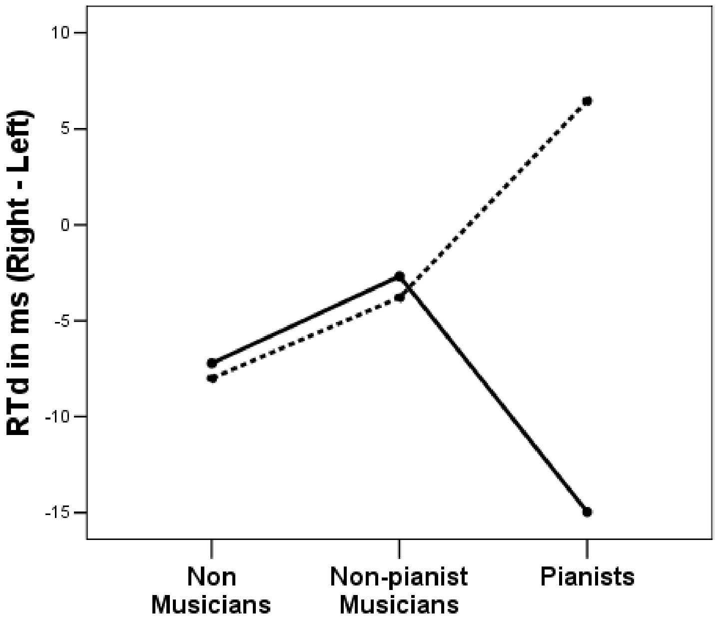

Figure 2: Interaction between Global pitch and Group. RTd between right-hand and left-hand responses as a function of Group and pitch-height. Solid line = high-pitched chords; dotted line = low-pitched chords.

The regression analysis appears to be more informative than the ANOVA. Adopting the method proposed by Lorch and Mayers (1990), a linear regression was computed for each participant, in which RTd were predicted on the basis of chord pitch and the regression slope was estimated. Negative regression slopes are an expression of strong association between left-hand responses and low-pitched chords, and between right-hand responses and high-pitched chords. The resulting regression slopes were entered in a single sampling t-test computed for each group of participants. Consistently with the results of the ANOVA, the regression analyses computed on the pianists indicated a significant negative slope [t(13) = -6.38, p = 0.001]. Conversely, neither the slopes of the non-pianist musicians nor of the non-musicians differed significantly from zero [t(13) = 0.998, n.s., and t(13) = 0.458, n.s., respectively] (Figure 3). These results were further investigated by entering the slopes of three groups in a one-way ANOVA to directly compare the mean slopes which emerged as being significantly different [F(2, 39) = 8.7, p = 0.001]. Post-hoc comparisons revealed that the mean slope for pianists (-0.620 ±0.471) was significantly different from those of both non-pianist musicians (0.042 ±0.473, p = 0.002) and non-musicians (0.005 ±0.471, p = 0.003), whereas no differences emerged between mean slopes for non-pianist musicians and non-musicians (p = 1).

Although the regression analysis did not distinguish between Global pitch and Local pitch, the pianist results point to a tendency towards a local pitch effect that was not detected by the ANOVA. As can be seen from the regression analysis plot (Figure 3), the pianists' left-hand responses are slightly faster for extremely low-pitched chords than for medium low-pitched chords. The same effect also appeared for right-hand responses.

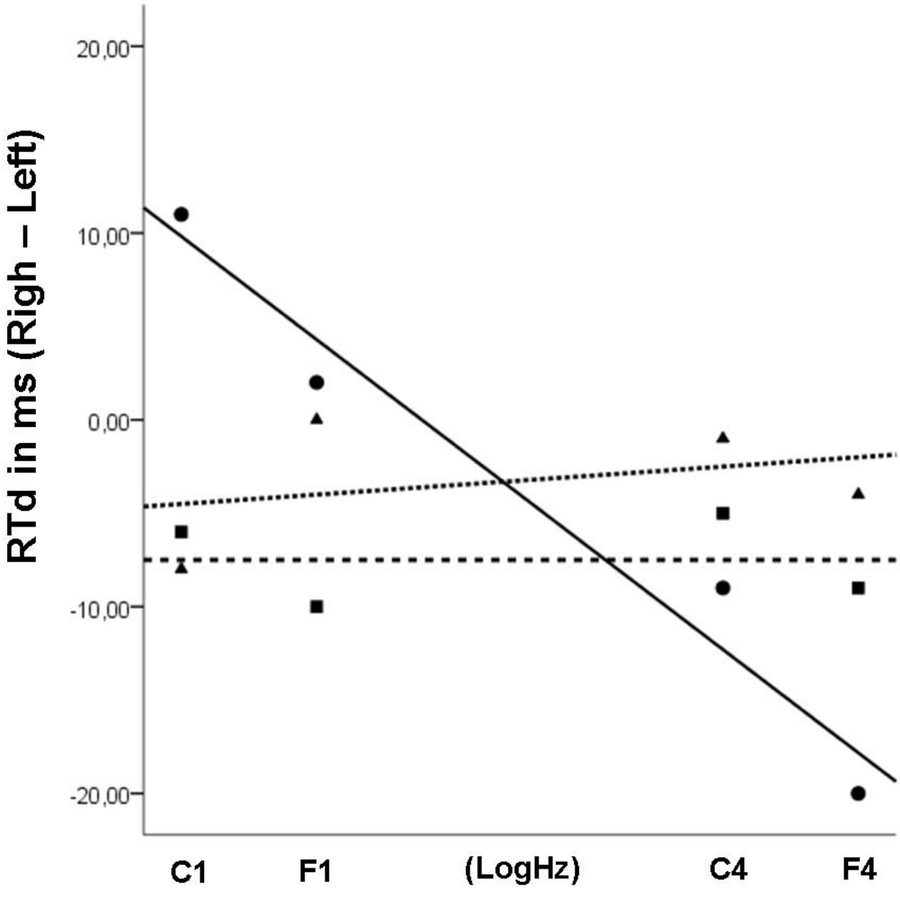

Figure 3: Observed data and regression lines of the RTd between right-hand and left-hand responses for pianists, non-pianist musicians and non-musicians as a function of pitch of the first note of the chord. Circles and solid line = pianists; triangles and dotted line = non-pianist musicians; squares and dashed line = non-musicians.

DISCUSSION

The aim of the present study is to assess whether the implicit processing of musical sound that varies along the low-pitched/high-pitched dimension primes motor responses. We tested three groups of participants (pianists, non-pianist musicians and non-musicians) with a shape decision task in which task-irrelevant auditory stimuli (high-pitched or low-pitched chords) were presented concurrently with visual stimuli. The ANOVA results suggest that only pianists have faster left-hand responses for the implicit processing of low-pitched chords, and faster right-hand responses for the implicit processing of high-pitched chords. This effect appeared in terms of global but not local pitch. Nevertheless, the regression analysis suggests a tendency to a local pitch effect. The phenomenon is not related to general musical competence, since non-pianist musicians did not show this effect. Results suggest the involvement of a motor representation. Pianists and non-pianist musicians share a common theoretical knowledge of music (e.g. reading skills, harmony rules), but procedural knowledge on how to execute pitch level is specific for their own particular instruments. Furthermore, the absence of the effect in the non-musician group rules out the hypothesis that a non-learned process may be involved in the genesis of the observed priming effect.

The TEC framework (Hommel et al., 2001) predicts that action effect processing evokes the corresponding action representation, set up on a common representational domain for action codes and action-effect codes. The acquisition of these representations would be related to repeated and contingent action-effect experiences. Our results concord with these assumptions; among our participants, only pianists had previous repeated and contingent action-effect experience related to sound production on a piano keyboard. As already mentioned, the structural organization of a piano keyboard is such that pianists learn that right-hand movements produce high-pitched sounds and left-hand movements low-pitched sounds. It is therefore reasonable to assume that the long training required to acquire skill on the piano would produce an integration between right-hand actions and high-pitched sounds, and left-hand actions and low-pitched sounds at the level of the common representational domain, so that the processing of high-pitched sounds (action effect) prime right-hand actions, and the same happens for low-pitched sounds and left-hand actions.

The tendency towards a local pitch effect emerged from the regression analysis (the lack of significance in the ANOVA may be due to low statistical power) suggesting a linear gradient in the effect. Pitch is represented at cognitive level in two dimensions, height and chroma. In the present experiment we specifically addressed the former dimension, which is linearly represented at mental level (Shepard 1982; Ueda and Ohgushi, 1987). We can therefore speculate that our results capture the pitch-height dimension (Cohen Kadosh et al 2008), however further investigation is required to verify this hypothesis.

When performing a musical instrument identification task of sounds with different pitches, musicians have been found to be faster on low-pitched tones with their left hand and on high-pitched tones with their right hand; this phenomenon is known as the Spatial Musical Association of Response codes (SMARC) effect (Rusconi et al. 2006; Lidji et al., 2007). The explanation offered for this effect is that “our cognitive system maps pitch onto a mental representation of space” (Rusconi et al., 2006, p 126). The pattern of results emerging from the present study rules out a possible explanation of our data based on the SMARC effect, since only pianists were faster on low-pitched chords with their left hand and on high-pitched chords with their right hand, whereas there no effect appeared in non-pianist musicians. As no distinction was made between the performance of pianists and non-pianist musicians in the two studies on the SMARC effect, our results may challenge an exclusively spatial interpretation of the phenomenon for the left-right dimension in the musician group. Compared to classical SMARC tasks (timbre discrimination or pitch-height confrontation), the procedure we adopted does not require voluntary processing of the auditory stimuli since the task is visual; moreover, we used chords instead of single notes. These differences may explain the inconsistent results. Further experiments are needed to provide new evidence of a possible auditory-motor interaction in the SMARC effect. Moreover, our results do not match those obtained with non-musicians in a pitch-height judgment task (Sonnadara et al. 2009, Experiment 1), which showed low tones facilitating responses with the left hand, and high tones facilitating responses with the right hand. This association effect along the horizontal dimension is in line with results obtained in experiments where participants are required to judge pitch height directly (Rusconi et al. 2006, Experiment 1). However, when pitch height is not explicitly involved in the task, the horizontal association effect disappears for non-musicians but not for musicians (see Rusconi et al. 2006, Experiment 2 and 3). Rusconi and colleagues suggest that for non-musicians this association depends on a linguistic clue, and the fact that it is not present in tasks where explicit pitch-height judgment is not involved seems to support this interpretation. In the same study Sonnadara and colleagues (2009) found a bias in localizing a high- or low-pitched sound with a pointer in the vertical (but not in the horizontal) plane (Experiment 2), while a bias for both planes emerged when the auditory stimuli were delivered through headphones instead of loudspeakers (Experiment 3). The authors do not account for the discrepancies in the results of Experiments 2 and 3. In our opinion the comment offered by Rusconi et al. (2006, p. 116) could be extended to Sonnadara’s results, namely that when pitch-height is directly involved in the task “one cannot say whether pitch height is spontaneously or mandatorily mapped onto space, and whether the assignment of high-frequency pitches to high (or right) locations and low-frequency pitches to low (or left) locations generalizes to a context where participants' main concern is not to locate or to represent pitches in space". Our study respects this constraint, since the auditory stimuli were the explicit target of the task, which could account for the inconsistency between our results and those of Sonnadara.

To conclude, the present results support the hypothesis that the pitch-height dimension has a role in the emergence of the auditory-motor interaction, but further studies are needed to provide a better understanding of the different components involved in this effect.

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