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Timmers, R. and Shen, L. (2016) Representation of Pitch in Horizontal Space and Its Dependence on Musical and Instrumental Experience. Psychomusicology: Music, Mind and Brain, 26 (2). pp. 139-148. ISSN 0275-3987

https://doi.org/10.1037/pmu0000146

Representation of pitch in horizontal space and its dependence on musical and instrumental experience

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Abstract

Representation of pitch in horizontal space and its relationship to musical and instrumental experience was examined in three behavioral experiments. Each experiment investigated the influence of a task-irrelevant dimension (pitch or location) on the perception of a task-relevant dimension (location or pitch, respectively). Sine tones with nine different pitches were presented from nine locations, and participants estimated the pitch or location of the stimuli. Experiment 1 showed an influence of the (task irrelevant) pitch of presented stimuli on the perceived location of the stimuli in musically experienced participants only. This influence increased with the degree of musical training of participants. No influence was found of presented location on the perception of pitch. Experiments 2 and 3 investigated the influence of instrumental expertise comparing the responses of a group of flutists with a group of pianists. An interaction with instrumental expertise was found only in Experiment 3, where participants played shortly on their respective instruments before doing the perceptual judgments. The experiments indicate that musical training in general influence the pitch-location association, and pianistic experience in particular.

Cross-modal correspondences; musical training; instrumental expertise; pitch perception; location perception, perceptual illusion

Introduction

Both musicians and non-musicians commonly employ visuospatial dimensions to represent or refer to auditory dimensions (e.g. Eitan & Granot, 2006). This is the case for example when describing musical aspects such as pitch as high or low, far or nearby (Eitan & Timmers, 2010), or when dancing or gesturing to music, and visualizing different aspects through movements of different size, speed, and direction (Küssner, Tidhar, Prior, & Leech-Wilkinson, 2014; Caramiaux, Bevilacqua & Schnell, 2010; Godøy, Haga, & Jensenius, 2006). Frequently observed mappings of pitch height include mappings onto vertical height, size, weight, visual sharpness and brightness (Eitan & Timmers, 2010; Walker, Walker, & Francis, 2012; Spence, 2011). Mappings of pitch onto horizontal location have also been shown (e.g. Weis, Estner, & Lachmann, 2015; Weis, Estner, Van Leeuwen, & Lachmann 2016), but are more ambiguous in direction (consensus about direction is relatively low, see Eitan & Timmers, 2010), and do not always show in speeded classification tasks. For example, depending on whether the task explicitly includes pitch or not, and includes a reference tone or not, non-musicians may not show an interaction between pitch and horizontal location, while musicians do (Lidji, Kolinsky, Lochy, & Morais, 2007; Rusconi, Kwan, Giordano, Umilta, & Butterworth, 2006; Lega Cattaneo, Merabet, Vecchi, & Cucchi, 2014). However, with sufficient focus of attention on the tones and, the effect may be observed also in non-musicians (Weis et al., 2015; 2016). It may be that associations between pitch and horizontal location differ in origin and/or development from e.g. the mapping between pitch and vertical location, and are less reinforced in everyday encounters with pitched sounds.

This paper investigates the dependence of the association between pitch and horizontal location on musical training, comparing responses from participants with three levels of musical expertise (Experiment 1), and two instrument groups (Experiments 2 and 3). Moreover, it will test the association between pitch and location by examining whether the unattended (task-irrelevant) dimension influences the perception of the attended (task-relevant) dimension. Previous studies have focused on the demonstration of an interaction between dimensions using a speeded binary response paradigm, as reviewed below. We will examine whether the location influences pitch perception and the pitch influences location perception in a continuous fashion (relatively high or low interferes in a continuous manner with relatively right and left, using a similar paradigm to Casasanto & Boroditsky, 2008 and Dolscheid, Shayan, Majid, & Casasanto, 2013). As a background to the study, we will shortly review main findings related to the association between pitch and vertical location, comparing these with findings on the association between pitch and horizontal location. This will bring us to the main hypothesis of the study that the mapping with horizontal location may be latently present in (right-handed) listeners, but is reinforced through music performance experience.

The mapping between pitch height and vertical location is a strong and robust association present in pitch-space synesthetes (Linkovski, Akiva-Kabiri, Gertner, & Henik, 2012) as well as the general population (Spence, 2011; Rusconi et al., 2006; Ben-Artzi & Marks, 1995). Participants make this association irrespective of reinforcement of the association through language, although language does seem to shape cross-modal correspondences. For example, in Persian, high and low pitch are commonly denoted as “thin” and “thick”, nevertheless Persian participants did show the association between high and low vertical space and high and low pitch (Dolscheid et al., 2013). This was in contrast to Dutch participants, who only showed an association between “thin” and “thick” and high and low pitch after reinforcement of the association by reading sentences linking the two concepts (Dolscheid et al., 2013). Interestingly, pre-lingual infants (4 month-old) have been shown differential responses to congruency in mappings for both associations: looking times were longer when a rise in pitch was associated with a rise in vertical location and the opposite for a fall in pitch (Dolscheid, Hunnius, Casasanto, & Majid, 2014; Walker et al., 2010). Similarly, they preferred the coupling of a “thinning” object with a rise in pitch, and a “thickening” object with a fall in pitch (Dolscheid et al., 2014). Walker and colleagues (2010) tested and confirmed the preference for congruency between pitch and sharpness of an object in infants. This provides evidence for the claim that neonatal perception is synesthetic (Maurer & Mondloch, 2006), and as such that several cross-modal correspondences are latently present from very early onwards.

On the other hand, it is not necessary for cross-modal correspondences to have an innate or a statistical basis (statistical in terms of observed associations in the real world). As Walker and colleagues (2012) argued and demonstrated, cross-sensory mappings occur at a conceptual level, giving rise to associations that are empirically unlikely. Due to frequent co-activation of sensory concepts such as high pitch, small size, and bright luminosity, links between uncorrelated concepts develop such as size and brightness (Walker & Walker, 2012).

Different methodologies have been used to demonstrate the association between pitch and vertical location. A common approach is to test interference between dimensions using speeded classification/discrimination or Stroop-like paradigms in which the properties of two presented dimensions are congruent or incongruent. For example, participants’ judgments are faster and more accurate when responding to higher pitches while presented concurrently with an object at a higher visual position (Melara & O’Brien, 1987) or verbal stimuli of the word “HIGH” (Melara & Marks, 1990) as compared to a concurrent presentation of an object at a lower visual position or the word “LOW”. Interference may occur when both dimensions are attended to (e.g. press a button when the object is high or the sound is high), but also when only one of the dimensions is attended to (e.g. respond to spatial height only), and the other is task irrelevant (see Spence, 2011 for a review). Interference may also occur between properties of the presented object and the response as tested in the so-called stimulus-response compatibility paradigm, where the response key (high or low, left or right key, small or large response object) is compatible or incompatible with features of the stimuli and the judgment made is relevant or irrelevant (e.g. judgment of timbre). Developing from a space-magnitude association (SNARC) in which task performance is better when responding to larger numbers with an upper button (Dehaene, Bossini, & Giraux, 1993), researchers found the space-pitch association (SPARC) that related to improved task performance when responding to higher pitches with the upper button (Lidji et al., 2007).

While most of these paradigms use a binary opposition between dimensions, Dolscheid and colleagues (2013) used a paradigm in which the influence of one dimension on the other dimension was tested on a continuous scale: Pitch of a sound and vertical location or thickness of a simultaneously presented object were varied in nine steps and presented in random combinations. The task of the participants was to reproduce (sing) the pitch after its presentation. Dolscheid and colleagues then tested the influence of the task irrelevant dimension on reproduced pitch.

Compared to vertical representations of pitch, horizontal mappings of pitch seem to be less ingrained and less omnipresent. Nevertheless, a systematic association has been found in some studies. Moreover, there is evidence that associations between horizontal location and pitch are stronger in musicians. By using the stimuli-response compatibility paradigm, Rusconi et al., (2006) found that participants' response speed and accuracy in a pitch comparison task (judging whether a target tone was higher or lower than the reference tone) was significantly affected by a preferential pairing between pitch and response position in the horizontal plane (as well as vertical): non-musicians tended to associate lower tones with left response locations and higher tones with right response location only when the task required to judge pitch explicitly; Musicians showed the low-to-left and high-to-right mapping when the task was pitch-related and pitch-unrelated (timbre discrimination). Similar results were found by Lidji and colleagues (2007), who investigated associations between isolated pitches and horizontal or vertical response positions as well as associations between the direction of melodic intervals and horizontal and vertical response positions, using pitch-related and unrelated tasks. The association between horizontal response locations and pitch was present in musicians irrespective of condition (related or unrelated, isolated pitch or melodic intervals). For non-musicians, a mapping of musical pitch onto the horizontal dimension only appeared in isolated tones, but not when processing melodic intervals. Surprisingly, an association between vertical response position and melodic interval was not found in either musicians or non-musicians.

Similar results supporting a left-right mapping of pitch in musicians were found by Lega and colleagues (2014) using a different paradigm. Participants indicated the midpoint of horizontal bars either visually or haptically, while hearing tones with different pitch heights over headphones. Judgments of musicians were influenced by the pitch height of the presented tones. This was not the case for non-musicians.

A possible origin of the horizontal mapping of sounds might be an orthogonal mapping from the vertical plane to the horizontal. Cho and Proctor (2003, 2006) showed that responses to stimuli with lower positions were improved by using left buttons and responses to stimuli with higher positions benefited from using right buttons (i.e. low-to-left and high-to-right mapping). Given the intuitive association between vertical height and pitch, Lidji et al., (2007) argued that lower tones which are perceived as lower in space are remapped onto left space and higher pitches are remapped onto right space. Steward, Walsh, and Frith (2004) also highlighted the orthogonal relationship between spatial locations on a piano keyboard and music notation, and suggested that the horizontal mapping may be particularly strong in pianists, although it has also been found in non-pianists.

Comparisons have also been drawn between space-number associations (SNARC, Dehaene, Bossini, & Giraux, 1993) and space-pitch associations (or space music, SMARC, Rusconi et al., 2006), since both can be ordered from low (left) to high (right), or, in an alternative conceptualization, from small (left) to large (right). Notably the association between pitch and magnitude differs depending on whether static tones (single high and low pitches) are presented or dynamic tones (pitch rises or falls, see Eitan, Schupak, Gotler & Marks, 2014). While isolated high and low tones are perceived as small or large (Parise & Spence, 2009), respectively, pitch rises are perceived as increasing in magnitude and pitch falls as decreasing (Eitan et al, 2014; Eitan & Granot, 2006). Generally, however, mappings found between laterality and pitch show the association between low-high pitch and left-right in space (Nishima & Yokosawa, 2009; Lidji et al., 2007), analogous to spatial mappings of low-high in number. This is the case when a reference tone is presented before the test tone, implicitly generating a pitch fall or pitch rise (Lidji et al, 2007). However, Weis and colleagues (2016) also found this association without using a reference tone, but using a sufficiently wide pitch range. Specifically, Weis and colleagues (2016) compared effects of number-response compatibility and pitch-response compatibility in a factorial design using spoken stimuli (spoken numbers at various pitches). They found both effects to operate independently of task relevancy. Moreover, the results showed a super-additive effect: the pitch-compatibility effect was stronger in the context of numeric incompatibility (relatively worse performance when both were incompatible). Notably, they found that the pitch compatibility effects on vertical and horizontal response dimensions occurred irrespective of the musical training of participants. The authors suggested that the difference in results for non-musicians compared to previous studies may be related to greater attention paid to the pitched sounds in their experiment, as they used pitched speech.

Adding to the complexity of the left-right mapping of pitch is the classical finding by Deutsch (1975; 1983) related to the so-called octave illusion. In her experiments, a conflict between pitch proximity and spatial proximity of presented stimuli is created that listeners tend to resolve by “relocating” pitches in space according to pitch height: high pitched stimuli are perceived to come from the right, while low pitched stimuli are perceived to come from the left. This relocation of the location of the pitches is however dependent on handedness of participants. It is in particular strong for right-handed participants. The illusion also occurs for dynamic stimuli: In Deutsch, Hamaoui, and Henthorn’s study (2007), synthesized tones were designed with varying left/right locations and high/low pitches. It was found that right-hand users (not necessarily musically trained) perceived the sequence as moving in a spatial dimension, in which sounds move from low-left when the pitch was lowest to a high-right point when the pitch was highest along an elliptical path. Left-handed participants did not show this percept.

These previous studies on associations between pitch height and vertical and horizontal space highlight some of the factors that reinforce or moderate the presence and strength of mappings that may be latently present in the general population. This includes language and the way we conceptualize auditory phenomena. It also includes neurological characteristics related to handedness and embodied experiences related to instrumental expertise. In this study, we will test this latter dependency, investigating the influence of musical expertise on the mapping between pitch height and horizontal space. We are not just interested in a binary mapping between left-low and right-high, but would like to see a more continuous mapping between the two dimensions in which lower is associated with more to the left and higher with more to the right. Moreover, we will investigate the occurrence of an illusion related to the association, rather than an interference of binary response categories, which has been the focus of most prior studies, and examine whether changes in a modality irrelevant for the task leads to an illusion of changes in properties of the target modality.

Experiment 1

All three experiments used the same basic methodology in which the effect of changes in one modality (i.e. location or pitch) was tested on the perception of the other modality (i.e. pitch or location). Experiment 1 was designed to examine the influence of musical expertise on these cross-modal interference effects between perceptual dimensions.

Method Experiment 1

Participants

A total of 33 volunteers participated in the experiment, grouped into three groups according to their level of musical expertise. The first group consisted of ten participants who were professional music teachers or musicians (Median Age=34.; Median Years of Musical Experience=27.5). Four participants of whom had piano as their main instrument. The second group consisted of eleven participants who had had extensive musical training (Median Age=22; Median Years of Musical Experience=11), but were not teaching or performing music at a professional level. Four of them listed piano as their main instrument. The third group consisted of the remaining 12 participants who had received no or very limited musical training (four years or less) (Median Age=27.5; Median Years of Musical Experience=0). One of these participants had played the piano, and one of them had recently picked up an instrument and was currently playing music. A Krukal-Wallis Test for independent sample confirmed that the three groups differed significantly in musical experience ($Chi^2(2,33)=27.493$, $p<.001$). Pairwise comparisons using Mann-Whitney U tests further confirmed significant differences in musical experience between the groups (Group 1 vs. Group 2, $Z=3.428$, $p=.001$; Group 1 vs. Group 3, $Z=4.060$, $p<.001$; Group 2 vs. Group 3, $Z=4.158$, $p<.001$). This result holds after adjusting the alpha value for multiple comparisons ($p<.008$). For ease of reference the three groups will be referred to as "non-musicians", "intermediate musicians", and "professional musicians". Four participants of the least musically experienced group were left-handed, and one participant of the most musically experienced group. All other participants were right-handed.

Material

The experimental stimuli consisted of 81 brief sinusoidal sounds derived by presenting sine tones with nine different pitch heights and from nine different horizontal locations. The sounds were 200 ms long with 5 ms of fade in and fade out at the start and end of the sounds, respectively. The nine pitches ranged from Eb3 (156 Hz), below middle C, to Eb5 (622 Hz), two octaves above, with intervals of 3 semitones. The amplitude of sounds was modified in accordance with equal loudness curves for sinusoidal sounds (Suzuki & Takeshima, 2004), in order to equalize the subjective loudness of the sounds. The subjective intensity was set to be constant at 75.35 dB(A), while the objective dB ranged from 90.97 dB for the lowest note (C3, presented as reference tone, see below), to 76.48 dB for the highest note (F♯5, presented as reference tone, as explained below)[1]. Stimuli and amplitude conversions were made in Audacity.

The nine sine tone stimuli were played back at nine horizontal locations, resulting in a total of 81 stimuli. The location of a sound was modified by changing the panning of the

[1] The online calculator of the DiracDelta Science and Engineering Encyclopedia was used for this. http://www.diracdelta.co.uk/science/source/a/w/aweighting/source.html#.UW6s6UrdKUQ

sound. Panning ranged from 80% towards the left of the middle to 80% towards the right of the middle (in case of 100% panning, the sound would come only from the left speaker or only from the right speaker). The sounds could come from nine positions in between these two extremes. The space between was regularly sampled. The speakers were 70 cm apart (distance between the two midpoints of the speakers). The participants were seated 80 cm away from the screen with a keyboard at close distance. The speakers were placed directly next to the screen.

Before the presentation of a target tone, two reference tones were presented (a low and a high reference tone) to facilitate the pitch judgment task. The low reference tone was three semitones below the lowest stimulus pitch (C3 below middle C, 131 Hz), while the high reference tone was three semitones above the highest stimulus pitch (F♯5, 740 Hz). These reference tones were presented with neutral panning (mid-point). No specific reference stimuli were provided for the location judgment. Instead, it was explained to the participants that the (visual) midpoints of the speakers functioned as references for the location judgment.

Procedure

After given informed consent, participants received a brief explanation of the experiment and four practice trials to get familiar with the task and the response interface. It was explained to the participants that the lines in the response interface related to the position of reference tones or locations, and that reference tones for pitch height would be presented just before each target tone, while reference positions for the spatial task were given by the mid-point of each speaker. Participants heard the 81 stimuli twice in random order (once to judge pitch and once to judge location), resulting in a total of 162 trials. Within each trial, the reference pitches were first presented followed by the target tone. Both the pitch and horizontal location of the target tone varied across trials. After the target tone, a prompt appeared (see

Figure 1) that asked participants to judge the pitch of the tone on a scale from 1 to 9 (low to high), or to judge the location of the tone on a scale from 1 to 9 (left to right). They used the horizontally aligned numbers on the computer keyboard to indicate their responses. They were then asked to press the space bar when ready to go to the next trial. The total duration of the experiment was less than 30 minutes.

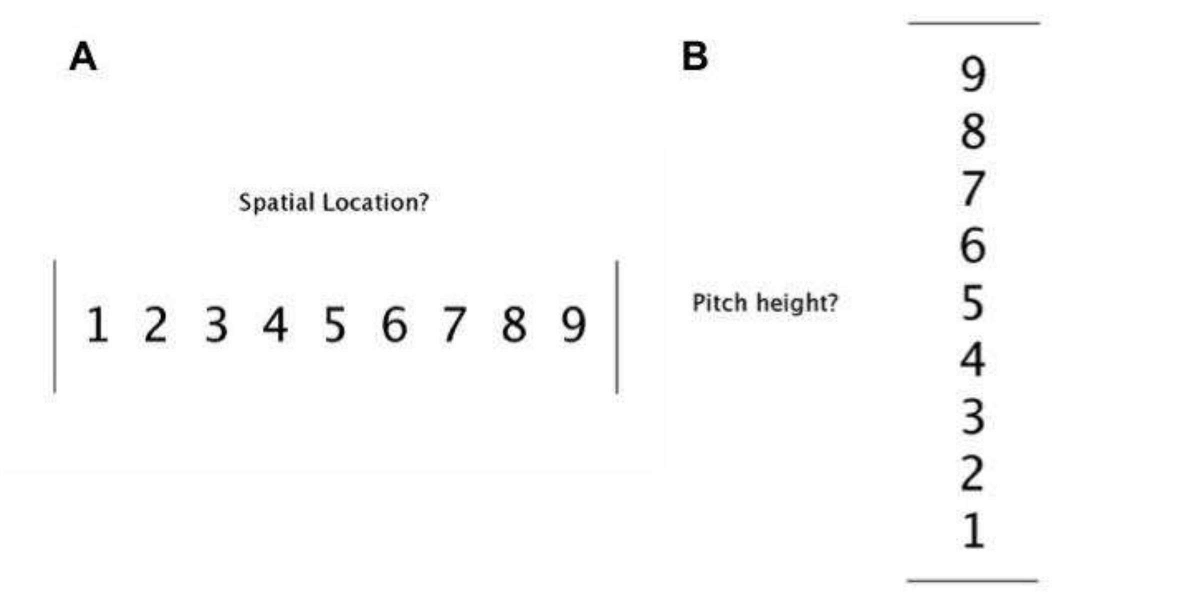

Figure 1. Illustration of the visual prompt indicating to the participants to judge the spatial location of the sound (Panel A), or the pitch height of a sound (Panel B) on a scale from 1 -9. Reference positions or tones are indicated using lines on either side of the extremes.

Data processing

For each participant, data consisted of 81 judgments of the pitch of the target tones, and 81 judgments of the location of the target tone. From this data per participant, four regression coefficients were obtained: The linear regression coefficients (unstandardized B) that captured the relationship between 1) the presented pitch of the target tone and the perceived pitch (81 data points per participant), 2) the presented location of the target tone and the perceived pitch (81 data points per participant), 3) the presented pitch of the target tone and the perceived location (81 data points per participant), and finally the presented location of the target tone and the perceived location (81 data points per participant). These four regression values were used as four data points per participant capturing two perceptual measures (judgments of perception and judgments of location) and their relationship to two features of the music (presented pitch and presented location). The regression values provide a measure of dependence of the subjective judgments on the presented musical feature: If the regression is close to 1, the two are perfectly related (e.g. perfect pitch classification based on pitch information). If the regression value is close to 0, there is no reliable relationship. While if the regression value is negative, the two are negatively related. Each of the regression measures showed a good spread across participants, which allowed for the employment of parametric statistical analyses.

Results Experiment 1

An ANCOVA was run with regression values related to the judgment of pitch and judgment of location as dependent measures and presented sound feature (pitch or location) as independent within-subjects variable. Level of musical expertise was added as between-subjects covariate, with levels 0, 1 and 2 for non-musicians, intermediate, and professional musicians respectively. Univariate tests showed significant main effects of sound feature on the judgments of pitch ($F(1,31)=49.126$, $p<.001$, $r=.783$), and on the judgments of location ($F(1,31)=20.136$, $p<.001$, $r=.628$). Inspection of the means in Table 1 shows that these main effects confirm what is logically expected: When judging pitch, regression values with the pitch of the sound were considerably higher than regression values with the location of the sound. The opposite was true when judging location.

Table 1: Mean regression values and standard error for judgments of pitch and location

	Pitch judgment		Location judgment	
	Mean	SE	Mean	SE
Pitch of stimulus	.461	.039	.192	.037
Location of stimulus	.034	.014	.476	.052

More interestingly, for the judgments of location, a significant interaction was found between level of musical training and the effect of sound feature ($F(1,31)=7.029$, $p=.013$, $r=.43$). No such interaction was found for the pitch judgments. Figure 2 shows the mean regression values for the location judgments of the three groups of participants. It shows that with growing expertise, the strength of the relationship between actual location and judged location goes down and the strength of the relationship between judged location and presented pitch goes up. Indeed for the two musician groups, the mean regression value of the relationship between judged location and presented pitch is significantly above 0 as tested using a one samples T-test ($t(10)=3.292$, $p=.008$ for intermediate musicians, $t(9)=3.838$, $p=.004$ for professional musicians). This indicates that location judgments of musically trained participants are influenced by the pitch of the sound, and this phenomenon strengthens with increasing level of expertise. The association in judgments is as predicted: low pitches are perceived to originate from the left, while high pitches are perceived to originate from the right.

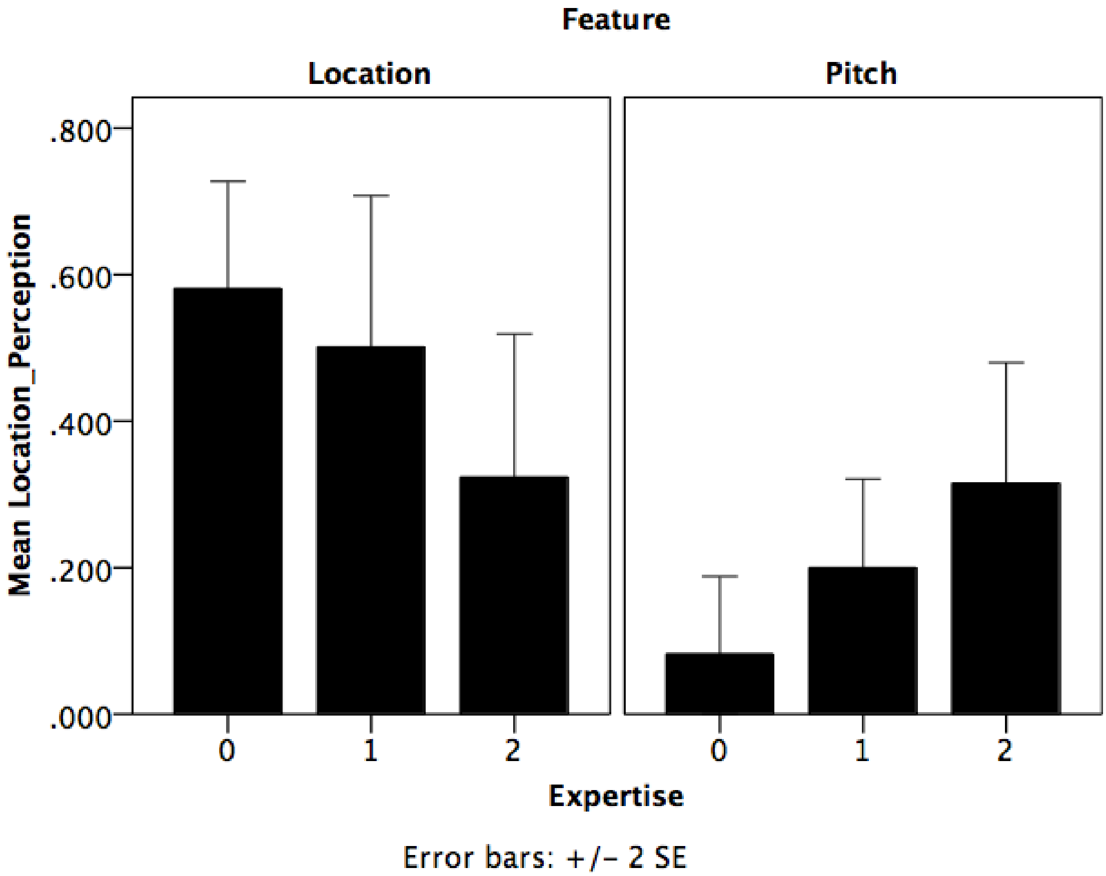

Figure 2. Mean regression values for location judgments per musical expertise group. The relationship between perceived location and presented location (left) decreases with increasing levels of expertise, while the relationship with presented pitch increases (right).

Discussion Experiment 1

The results of Experiment 1 confirmed a task-irrelevant mapping between horizontal location and pitch in musically trained participants, but in an asymmetric manner: while presented pitch influenced perceived horizontal location, presented location did not influence perceived pitch. The lack of an influence of horizontal location might be related to the fact that, in our experiment, horizontal location was varied as an auditory dimension rather than a visual dimension. A visual prompt is likely to exert a stronger influence on perception (Sinnett, Spence & Soto-Faraco, 2007). We leave this question for future consideration. For now, we are interested in more closely examining the observed interaction with musical expertise: Does musical training in general give rise to an interference between judged location and presented pitch, or is particular instrumental expertise responsible for this interaction? In particular, what is the relevance of intimate familiarity with the pitch layout of the piano for this interaction to occur? Does the interaction also occur when playing an instrument with an opposite layout such as the flute, where high pitch is mapped towards the left and low pitch towards the right?

Experiment 2

Experiment 2 was designed to test the effect of instrumental expertise on the mapping of pitch onto horizontal space. It was predicted that pianists would show a stronger association between low to high pitch and left to right horizontal location, than flutists, who may not show this association, or even show an opposite association between low to high pitch and right to left horizontal location. Although the mapping of pitch on a flute is not as continuous as on a piano, a basic C major scale going up in pitch is associated with a movement from right to left if one holds the flute to the right and thinks in terms of opening (or closing) holes on the flute, and the accompanying finger movements that are associated with it. Experiment 2 employed the same methodology as Experiment 1, except that different populations of participants were compared. Additionally, Experiment 2 tested location and pitch perception in two different blocks rather than in an interleaved manner as in Experiment 1. This strengthens the notion that the task-irrelevant dimension is indeed task-irrelevant. If an influence of the unattended dimensions is still found, this provides even stronger evidence of an automatic mapping of the dimension.

Method Experiment 2

Participants

Two groups of volunteers participated in this experiment consisting of 10 participants who played flute as their main instrument and 12 participants who played piano as their main instrument. The two groups were comparable in musical training (Median=13.75 for pianists, Median=12 for flutists) and in hours of playing per week (Median=9.5 for pianists, Median=7.5 for flutists). An independent-samples Mann-Whitney U Test indeed showed no significant difference between the groups in musical experience ($Z(22)=-1.863$, $p=.063$) or the number of hours of playing per week ($Z(22)=-0.596$, $p=.551$), Two of the flutists were left-handed and one of the pianists. Age range was comparable for both groups (between 18 and 26) although data about this aspect was incomplete because not all participants had indicated their age on the response form. Among the flutists was one male participant, while five of the pianists were male. This gender division can be seen as typical for these instrument groups.

Material

The material was the same as in Experiment 1.

Procedure

The same procedure was followed as in Experiment 1, including taking informed consent, explaining and practicing the tasks, which was followed by the main experiment. The only change in experimental procedure concerned the decision to block the judgments of pitch and location and to counter-balance the block order, rather than to ask participants to do the judgments in random order. This procedure was clearer for participants, and experimentally stronger: Confirmation of the influence of the other modality when the judgments are separated gives stronger evidence of an influence of the unattended dimension on the attended dimension than when the judgments randomly alternate in a task.

Results Experiment 2

The same data processing procedure was followed as in Experiment 1. Subsequently, the analyses focused on four data points per participant, which captured the relationships between perceived location and pitch, and presented location and pitch. A mixed model ANOVA was run with sound feature as within-subjects independent variable and musical training as between-subjects independent variable. Dependent measures were perception of pitch and perception of location. Univariate tests showed a strong effect of sound feature on the perception of pitch ($F(1,17)=141.346$, $p<.001$, $r=.936$). The pitch of the sounds contributed much more strongly to the perception of pitch (mean regression=.539, SE=.035) than the location of sounds, whose influence was negligible (mean regression=.007, SE=.017), see also Figure 3. There was no significant interaction between instrumental expertise and the effect of sound feature ($F(1,17)=0.201$, $p=.659$, $r=.316$). Nor was there a main effect of instrumental expertise ($F(1,17)=0.388$, $p=.540$, $r=.436$).

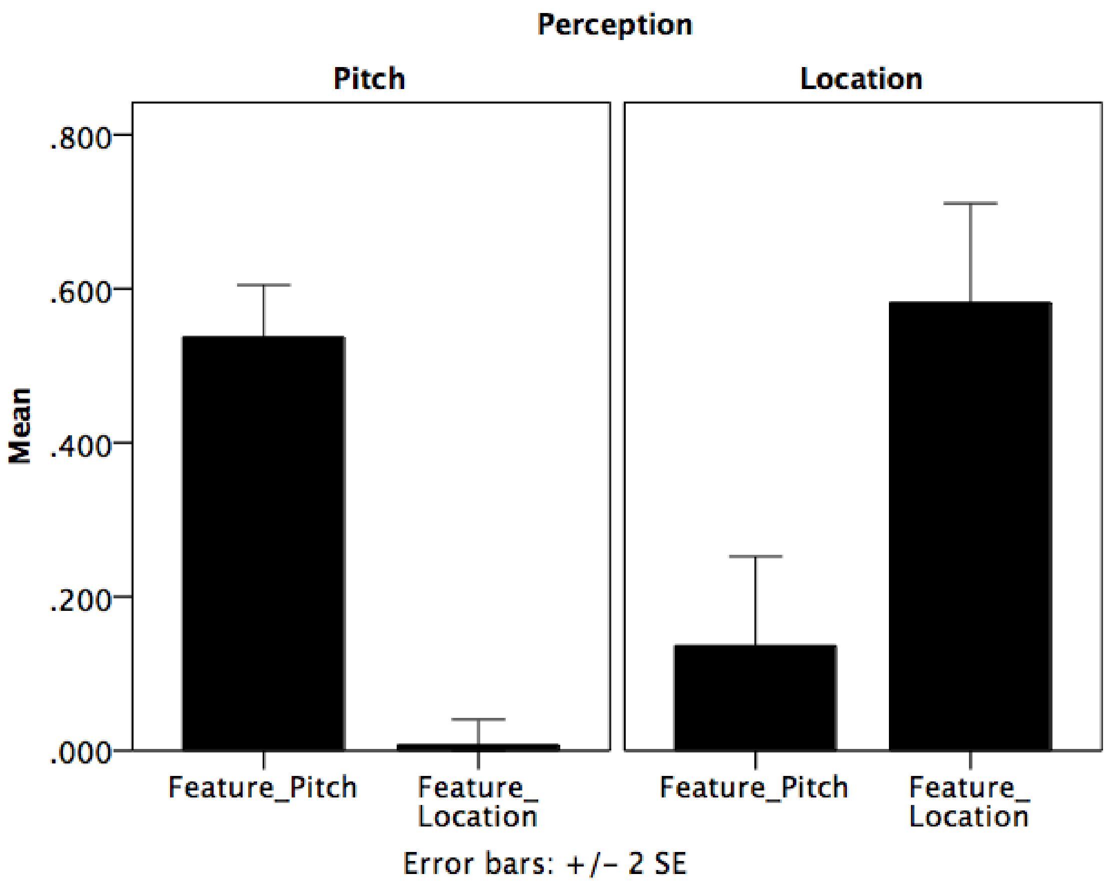

Figure 3. Mean regression values for pitch judgments (left) and location judgments (right). Pitch judgments were solely dependent on presented pitch. Location judgments depended significantly on both, though more strongly on presented location than presented pitch.

The perception of location was also influenced by a significant main effect of sound feature ($F(1,17)=13.718$, $p=.001$, $r=.638$). However this effect was not as strong as for the perception of pitch (paralleling Experiment 1). In other words, the difference in strength of a sound feature's contribution to the perception of location was smaller than was the case for the perception of pitch (see Figure 3). There was no significant interaction between instrumental expertise and the effect of sound feature ($F(1,17)=0.148$, $p=.704$, $r=.084$). There was also no significant main effect of instrumental expertise (F(1,17)=1.860, p=.188, r=.292). In general, the flutists and pianists performed in similar ways (see Table 2).

Table 2: Mean regression values, SE, and 95% confidence intervals for the relationships between a sound's pitch or location and perceived location in flutists and pianists.

			95% Confidence Interval	
	Feature	Mean (SE)	Lower Bound	Upper Bound
Flutists	Pitch	.086 (.087)	-.095	.268
	Location	.583 (.090)	.378	.788
Pianists	Pitch	.177 (.079)	.011	.343
	Location	.580 (.090)	.393	.767

A one samples T-test was run to examine whether the regression values between presented pitch and perceived location were reliably higher than 0. This was indeed the case (t(21)=2.336, p=.029). In other words, location judgments were influenced by the pitch of the sounds, in addition to being strongly related to the location of the sounds.

Discussion Experiment 2

Experiment 2 showed that flutists and pianists are principally not performing differently from each other. Both groups only relied on a tone's pitch when judging pitch, and relied more strongly on a tone's location when judging location than on a tone's pitch, although the pitch of a tone also influenced the location judgments. This influence of pitch on perceived location was reliably different from 0, but not very strongly so. The influence of pitch on location perception was comparable to the performance of the group of intermediate musicians in Experiment 1 (mean regression value of .200), although the influence of pitch was slightly lower in Experiment 2 (mean regression value of .136). The smaller influence could be due to the difference in experimental procedure between the two experiments (see for a comparable reductions depending on experimental paradigms, Casanto & Boroditsky, 2008).

The lack of an interaction with instrumental expertise suggests that irrespective of the pitch layout of the primary instrument of a musician, an association between left-right location and low-high pitch is present that is sufficiently strong to influence location judgments. An alternative explanation for the presence of a null effect of instrumental expertise could be a lack of statistical power to demonstrate an effect. However, this is unlikely to be the case, since the effect sizes were minimal. In this respect, the null effect seems genuine even with only a small sample of participants. One possible explanation that musical training in general increases the influence of pitch on perceived location is the prominence of pitch in music perception and music production (e.g. Peretz & Coltheart, 2003). Musicians may prioritize the processing of pitch over the processing of the location of the sound. Additionally, most musicians are well familiar with the layout of a piano and the left-right mapping of low to high pitch seems to have prominence over other mappings (as possibly explained by an orthogonal mapping between vertical height and horizontal height, see Cho & Proctor, 2003). The focus on the pitch of sounds in musicians may be sufficient to activate mappings between location and pitch that are latently present.

Nevertheless, we wanted to investigate the possibility that instrumental experience influences the mapping between pitch and horizontal location one step further. It may be that flutists and pianists do not differ in this mapping in a “cold” perceptual task. However, what if they have just played their respective instruments? Does performing the piano strengthen the left-right mapping of low to high pitches? And does performing the flute decrease this tendency or even induce an opposite mapping of pitch? Brief exposure to particular cross-domain mappings (for example by reading sentences that imply the mappings) have been shown to influence subsequent perceptual performance before (Dolscheid et al., 2013). These questions are addressed in Experiment 3.

Experiment 3

Experiment 3 was designed to test the influence of instrumental experience on the mapping between pitch and horizontal location. It was predicted that playing on a musical instrument with a certain pitch layout would activate the pitch-horizontal location mapping in instrumentalists strongly familiar with that instrument. The activation of this association would strengthen the left-right mapping of pitch in pianists and weaken this mapping in flutists, or even activate reverse mappings of pitch in flutists. To test these predictions, flutists and pianists were asked to perform a number of brief exercises before doing the perceptual task of judging the location or pitch of target tones. The exercises were only brief, since we assumed that even brief exposure would activate knowledge that is already present. Participants were not asked to learn new mappings, but played on the musical instrument that was highly familiar to them.

Method Experiment 3

Participants

Eighteen volunteers participated in the experiment. Among them were nine flutists and nine pianists. The pianist group had slightly more musical experience (Median Years of Musical Experience=16) than the flutists (Median Years of Musical Experience=12), but an independent samples Mann Whitney U test indicated that the difference was not statistically significant ($Z(18)=-1.905$, $p=.057$). The pianist group was overall a bit older in age (Median Age=23) than the flutists (Median Age=20), which was confirmed to be a statistically significant difference by an independent samples Mann Whitney U test ($Z(18)=-1.905$, $p=.036$). Only one of the participants (a pianist) was left-handed. The others were right-handed. One of the flutists was male, and three of the pianists.

Material

The volunteers performed three brief exercises on their instrument. The same exercises were used for both instruments and prompted the volunteers to play sequences of up and down going pitches (scales and arpeggios), implicitly emphasizing the lay out of relatively high and low pitches on the instrument.

Procedure

Volunteers were asked to come to the music psychology lab of the music department. Flutists were asked to bring their instrument, while pianists were asked to play the Yamaha upright piano located in the lab. After an explanation of the experiment and giving informed consent, the volunteers were given three simple exercises to play. It was assumed that no warm up was needed, although participants were given time to tune their instrument or briefly play the instrument to get comfortable. An exercise was played three times, before continuing to the next exercise. The order of the exercises was fixed. The first and third time that an excerpt was run through, the volunteer played the excerpt as usual at a self-chosen speed. The second time, however, participants played the excerpt silently. That is he or she made the finger movements without producing a sound. This variation was added to maintain interest and attention to the task, and to direct attention to the movements related to the production of the sounds.

After the performance of the exercises, which took around five minutes, the volunteers participated in the perceptual experiment, which was identical in material and procedure to Experiment 2. The session was closed with a debriefing. Informed consent and details about background and musical training were recorded at the start of the session.

Results of Experiment 3

Data processing was identical to the procedure used in Experiments 1 and 2. Consequently four regression values were used as data points per participant, providing measures of two types of responses (pitch perception and location perception) and their relationship to two features of the musical stimuli (presented pitch and location). A mixed model ANOVA was run with sound feature as within-subjects variable and instrument as between-subjects variable. Dependent variables were perception of pitch and perception of location as two separate measures. The results for the perception of pitch were similar to the results in Experiments 1 and 2. There was a strong effect of sound feature on the perception of pitch ($F(1,16)=41.220$, $p<.001$, $r=.849$): Reliance on the pitch of the sound was strong ($M=.509$, $SE=.060$), while the location of the sound did not influence the pitch judgments ($M=.025$, $SE=.060$). There was no significant interaction with instrumental experience ($F(1,16)=0.002$, $p=.967$, $r<.004$), nor was there a main effect of instrumental experience ($F(1,16)=0.437$, $p=.518$, $r=.164$).

Of particular interest were the results for the location judgments. As before, there was a main effect of sound feature ($F(1,17)=9.337$, $p=.008$, $r=.607$). However, the effect size was considerably less strong than for pitch judgments, which is related to the double reliance of location judgments on pitch as well as location. Moreover, there was a significant interaction between the effect of sound feature and musical experience ($F(1,17)=5.647$, $p=.030$, $r=.511$). There was a significant main effect of instrumental experience ($F(1,17)=5.399$, $p=.034$, $r=.502$), related to a higher regression value overall for the flutists, reflecting their better performance of judging the location based on the presented location, which raises the average regression value.

The interaction between instrumental experience and the effect of sound feature for the judgment of location was examined further. Inspection of the means (see Figure 4) indicates that, while flutists rely much more strongly on location than pitch when judging location, the judgments of the pianists were equally influenced by the pitch of the sounds and the location of the sounds. Separate analysis of the effect of sound feature for pianists and flutists on the judgment of location confirmed this interpretation. For flutists, the effect of sound feature on the judgment of location was significant ($t(8)=4.981$, $p=.001$). However, for pianists, this effect was absent ($t(8)=0.405$, $p=.696$).

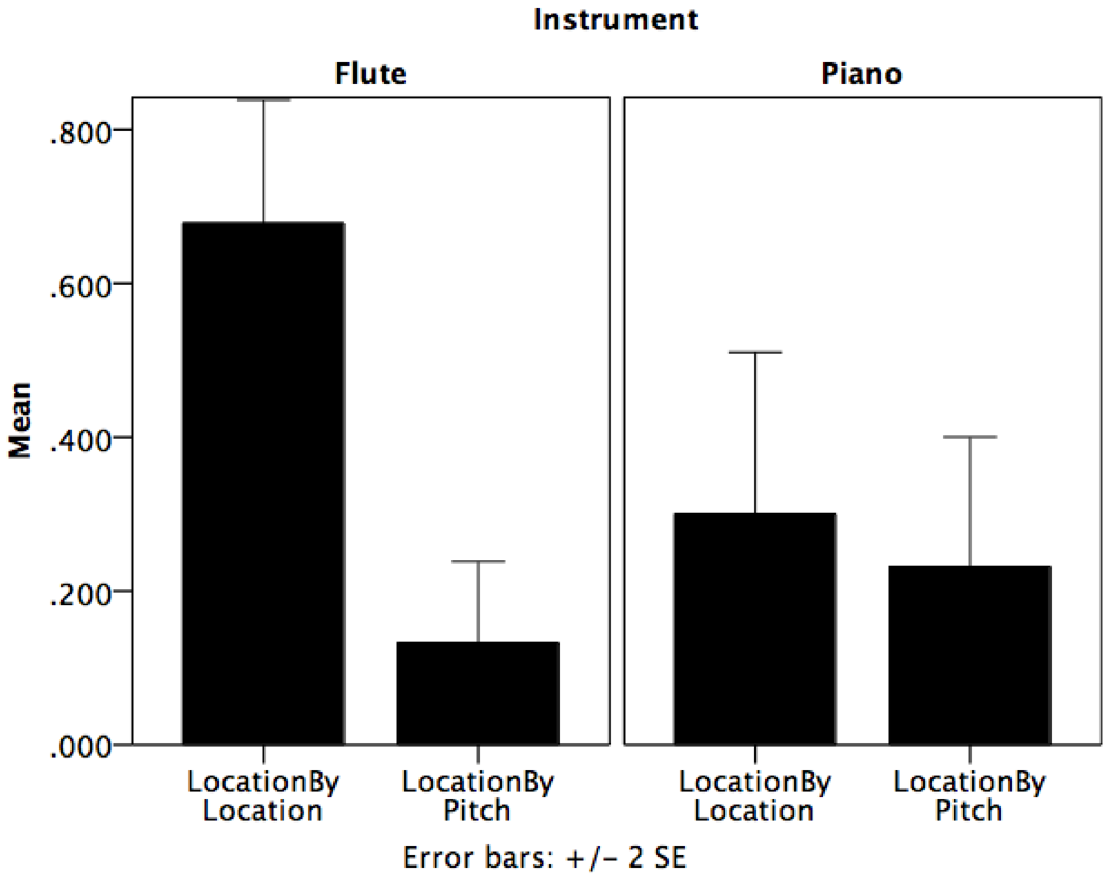

Figure 4. Mean regression values for location judgments for flutists (left) and pianists (right). For flutists, perception of location relied more strongly on presented location than on presented pitch. For pianists in contrast, perception of location relied equally strongly on presented location as presented pitch.

One-samples t-tests were conducted to check whether the regression values between the pitch of a sound and the perceived location of a sound were significantly larger than 0. A separate analysis was done for flutists and for pianists. For both instrument groups, the mean regression value was significantly larger than 0. This difference was stronger for the pianists ($M=0.232$, $t(8)=2.750$, $p=.025$) than the flutists ($M=0.133$, $t(8)=2.511$, $p=.036$).

Discussion Experiment 3

In Experiment 3, there was a significant interaction between instrumental experience and the mapping of pitch onto horizontal location. It was not the case that performing the flute reduced or reversed the mapping between pitch and horizontal location. Instead it seemed that performing the piano strengthened the left-right mapping of pitch height, resulting in an equal reliance on pitch and location when judging location.

The professional musicians in Experiment 1 showed a similar equal reliance on pitch and location when judging location. A Mann-Whitney U Test confirmed that there was a significant difference in years of musical experience between the pianists of Experiment 3, and the advanced musician group of Experiment 1 ($Z(19)=-2.740$, $p=.006$) as is also apparent from their median years of musical experience (Median=16 for the pianists of Experiment 3, and Median=27.5 for the advanced musician group of Experiment 1). On the other hand, the pianists of Experiments 2 and 3 were of comparable levels of musical training as confirmed by a Mann-Whitney U Test ($Z(22)=-1.322$, $p=.186$), although there was a trend for the pianists in Experiment 3 to be more experienced (Median=16) than the pianists in Experiment 2 (Median=13.75). The flutists of Experiments 2 and 3 also did not differ in their level of musical training as confirmed by a Mann-Whitney U test ($Z(19)=-.124$, $p=.901$) This suggests that active musical performance on the piano indeed increased the influence of pitch on spatial location judgments. In contrast, brief performance on the flute did not result in an increase of the influence of pitch on spatial location.

General Discussion

The main finding of the three experiments was that musical experience in general, but also active experience with performance on the piano strengthen the illusion that sounds with a low pitch come from the left, while sounds with a high pitch come from the right. The illusion or cross-domain interference was observed between perceived location and the pitch of the presented sounds. It was not observed between perceived pitch and presented horizontal location of the sounds. Listeners did not perceive the pitch of a sound to be lower because it came from the left. We briefly discussed the absence of this influence of location on pitch perception in the discussion of Experiment 1. It may be that if we strengthen the prompting of the horizontal location of a sound, for example by showing a visual location on the screen, the horizontal location does influence perceived pitch. Similarly, it may be that a different task, such as a vocal production task, would show an interference between horizontal location and pitch production, analogous to the interaction between pitch-production and vertical height found in Dolscheid et al. (2013) On the other hand, the relative reliability of pitch perception compared to location perception may not come as a surprise. Indeed, the strength of the orientation to pitch in musicians is part of the reason why we think musicians show a cross-domain interference between presented pitch and location perception. As mentioned before, pitch is a primary feature varied in music, in contrast to location, which is, in most genres, much less systematically and abundantly varied. This means that perception of location is not primary for most musicians, in contrast to perception of pitch. Improved processing of pitch in both music and language has been demonstrated to be one of the outcomes of musical training (see e.g. Schön, Magne, & Besson, 2004; Magne, Schön, & Besson, 2006). In this context, it is interesting to note that some musical training, in particular conducting, does foster improved horizontal location perception through the need to localize and differentiate between instruments and instrumentalists (Nager et al., 2003).

While musical training seems to strengthen interference effects between pitch and perceived horizontal location of sounds, some previous studies did show interference effects between pitch and horizontal location in non-musicians, using speeded response compatibility paradigm. Two studies in which this was the case used piano and/or vocal sounds as stimuli (Weis et al., 2015; 2016). Using sounds with particular timbres (e.g. piano, flute and voice) may indeed influence the pitch-location interference effects – a hypothesis warranting further investigation.

Opposite mappings between pitch and location were not observed where low pitch would be associated with a location towards the right. Indeed, it may be harder, although not impossible for the opposite mapping to occur. Deutsch and colleagues (1983, 2007) found that right-handed participants mapped high sounds to the right and low sounds to the left in the so-called octave illusion experiments. Left-handed participants did not show this mapping. However, they also did not show the opposite mapping. Interestingly, Casasanto (2009) did find some mappings to change direction depending on handedness. This concerned for example gestures related to categories perceived as being “good” or “bad”, with the active hand denoting the “good” side. Indeed, some left-handed pianists have argued for pianos to be mapped in the opposite direction (low to the right)[2]. This is related to the virtuosity and expression of what the hand must play, which gives a link between pitch and hand, rather than strictly speaking pitch and horizontal location.

Experiment 3 stressed the relevance of embodied experience for the illusion to be activated. Nevertheless, this may not be the only way in which illusions between perceptual domains may come to occur, although the influence of embodied experiences may be relatively strong. More symbolic or representational factors play a role as well. This concerns for example the way pitch is represented on a score, and the way we speak and conceptualize pitch. Direction of reading may influence our conceptualizations of space and horizontal location, as demonstrated in children who learned to read in Arabic compared to French (Fagard & Dahmen, 2003). These examples indicate that the mappings of modalities are more

[2] See for example http://lefthandedpiano.co.uk/about.html

flexible than we may think based on investigations of relatively homogeneous participant groups.

A limitation of the presented experiments is that they all used a numerical response mode. Replicating the experiments using a different response mode (or reversed numerical mapping) is necessary to demonstrate that the results are independent of a pitch-space-numerical magnitude mapping. The absence of an effect of presented location on pitch perception suggests that the responses were indeed independent of response mode, since presented location and the left-right orientation of the numerical responses are closely associated, but this did not show up in the pitch judgments. The mapping of pitch onto numerical magnitude is relatively ambiguous (Eitan & Timmers, 2010), since high pitch is perceived as small (and low pitch as large), as well as high in space (while low pitch is low in space (see e.g. Spence, 2011). The response paradigm used in the presented experiments emphasized one particular mapping (left-right to low-high). While this disambiguates the mapping, it does not necessitate a cross-domain interaction effect. The task was also done without a time constraint, making confusions due to task demands less likely to occur.

In summary, this study showed compelling evidence of the association between low to high pitch and left to right location through the demonstration of an illusion that sounds come from a certain location depending on their pitch. This illusion was only present in musically experienced participants. The illusion was stronger for more experienced musicians, and in pianists after performing their instrument, indicating that both long-term and short-term training strengthens the association.

Acknowledgements

The research was realized with financial support from the British Academy, International Partnership & Mobility Scheme, award number PM120092 to Renee Timmers and Zohar

Eitan. We are grateful to Zohar Eitan, Roni Granot, Nikki Dibben, Peter Walker and Daniel Casasanto for ideas and discussions related to the project. We are further indebted to the MA students of 2013-2014, Jessica Crich, Kathy Dilworth, Rawatsira Issarakul, Barbora Kerkova, Tim Metcalfe, Courtney Mulligan, Binyang Wang, and Yunhao Zhao, for their help with data collection for Experiment 2. Parts of the study were presented at the Neurosciences & Music Conference V: Cognitive Stimulation and Rehabilitation 2014, International Conference on the Multimodal Experience of Music 2015, and the Ninth Triennial Conference of the European Society for the Cognitive Sciences of Music 2015.

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