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Effects of musical training, timbre, and response orientation on the ROMPR effect

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Abstract

Music perception involves multisensory perception. In this study, the impact of timbre on the interaction between pitch-space crossmodal correspondences and response orientation (the ROMPR effect) as explored across two experiments. Participants were examined in both auditory and visual stimuli, then were asked to judge the pitch of the auditory stimulus they heard. Tones were presented in different timbres for each experiment: Experiment 1 examined the impact of timbre on the ROMPR effect by comparing piano and flute tones. Experiment 2 examined the effect of differing response orientation on the presence and strength of the ROMPR effect in the context of cello tones. In the first experiment, results showed that piano tones have a stronger ROMPR effect than flute tones at high pitches, likely because of the piano's construction, which is congruent to the horizontal orientation. Also, a stronger ROMPR effect was found on low pitches comparison to high pitches. The results of the second experiment showed that response orientation affects the presence and directionality of the ROMPR effect, but that this feature is mediated by musical ability. Specifically, only those with above-median musical abilities demonstrated the horizontal ROMPR effect in the congruent condition. Overall, these findings suggest that timbre plays a role in the strength of the ROMPR effect only to the extent that the timbre can be associated with the spatial orientation of the source of the sound. This adds to a mixed literature, where many of the observed effects are relatively small in magnitude, and suggests the need for additional large-sample studies to draw firmer conclusions.

Keywords: stimulus response compatibility, pitch-space crossmodal correspondences, timbre, ecological valid sound

Declarations

Funding

There is no funding to declare for this project.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval

This research was approved by the Research Ethics Board at the University of New Brunswick Saint John (File# 033-2018).

Consent to participate

All participants gave informed consent to participate in this experiment.

Consent for publication

All participants gave informed consent to have their anonymous data included in a publication.

Availability of data and material

All data for these two experiments are available publicly on the Open Science Framework at: https://osf.io/xuamw/.

Code availability

No code is available for these experiments, as analysis was conducted in GUI-based software.

While traditionally studied based on single modalities, we now understand perception to be a multisensory process. There are numerous ways in which stimulus features of one modality may affect the perception of features in a different modality, including the congruency between those features (e.g. Parise & Spence, 2008; 2009; Doehrmann & Naumer, 2008). One well-known correspondence in perception is the tendency to associate auditory pitches on a vertical axis, with higher pitches being perceived as originating from higher in space and lower pitches being perceived as originating from lower in space. This effect has been observed in lab studies (Pratt, 1930; Bonetti & Costa, 2017), has also been confirmed through recordings of real-life stimuli (Parise et al., 2014). While the mapping of pitch to vertical space seems to be relatively universal, mapping pitch to horizontal space tends to occur more prominently in trained musicians than in non-musicians (Lidji et al., 2007; Lega et al., 2014), likely because specific pitches are more likely to be repeatedly paired with certain spatial points throughout musical training and performance, forming these associations (Stewart et al., 2013). However, there is also recent research that showed – rather emphatically – that there was no advantage for trained musicians on these kinds of tasks (Pitteri et al., 2020). While there are findings in both directions within the literature, it is also important to note that further research is required with a larger number of participants than have been recruited in the past, and this study is an attempt to provide some of this kind of data.

One of the most well-known stimulus-response correspondences is the SMARC effect, which consists of mapping our internal representation of pitch onto the orientation of a response device. Participants tend to respond more quickly and accurately when response devices are mapped congruently (e.g. high pitches responded to with high buttons, and vice versa) than when they are mapped incongruently (e.g. high pitches responded to with low buttons). The SMARC effect has been examined in sagittal (Rusconi et al., 2006) and horizontal (Sonnadra et al., 2009; Guilbert, 2019) contexts, the findings show that the vertical effect seems to be more robust, especially in non-musical-expert populations. To examine the SMARC effect, one must contrast congruent response mapping with incongruent response mapping along the same response dimension. Klapman et al. (2020) did not strictly do this, rather examining effects of congruent response dimension (e.g. vertical response orientation with vertical effect) and incongruent response dimension (e.g. vertical response orientation with horizontal effect). The findings demonstrated that when response orientation was vertical, only vertical pitch-space orientations were statistically significant. When response orientation was horizontal, however, both vertical and horizontal pitch-space orientations were significant. As such, Klapman et al. (2020) concluded that vertical pitch-space interactions are more universal and occur at a perceptual level while horizontal pitch-space interactions occur only when a congruent response mapping exists, meaning that this interaction occurs at the level of response (cf. Calvert & Thesen, 2004; early vs. late multisensory integration). Hence, this was deemed the Response Orientation Modulates Pitch-space Relationships (ROMPR) effect.

The interaction between pitch and space has been explored to a great extent previously (e.g. Leboe & Mondor, 2007; Walker, 2012; Eitan & Timmers, 2010; Dolscheid et al., 2014). Previous research from our lab revealed that pitch-space interactions are modulated by response mapping (Klapman et al., 2020). This is an interesting finding, but this research employed artificially created sine tones as auditory stimuli, and the tones are not the only element be used for music or sound perception. There are three primary dimensions of sound: pitch, loudness, and timbre (Melara & Marks, 1990). Pitteri et al. (2017) found that participants are better able to discriminate amongst tones when the pitch and brightness of a tone match. They suggested that the observed pitch-space interactions are not due to the manipulation of the pitch-height alone but arise because of a coherent change of pitch-height and brightness. Other research has found that participants who hear percussive tones perform significantly better at recognition, learning, and memory compared to participants who hear flat tones (Schutz, Stefanucci, Baum, & Roth, 2017). It is also important to consider the ecological validity of the tones used in research, and the potential effects on replicability that this may have. In a recent survey of the field, Schutz & Gillard (2020) found that the majority of auditory stimuli used in research are artificial tones, but that findings from these tones often do not generalize to real-life scenarios. As such, the current research will employ non-artificial stimuli.

In this paper, we present two experiments conducted to ascertain the effects of using naturalistic sounds in a pitch-space response mapping interaction task. In Experiment 1, we examined the effect of using tones from piano and flute on this effect. We hypothesized that piano sounds would demonstrate a stronger effect than flute sounds, particularly on the horizontal effect. This is due to nature of the construction of the piano: low pitches at the left side, which are mainly played by the left-hand; high pitches at the right-side, which are mainly played by the right hand. The flute has the reverse construction of the piano: the right-hand controls low pitches and the left-hand controls high pitches. This is incongruent with the traditional direction of effects such as the SMARC effect, as well as our response mapping manipulation. In Experiment 2, we examined the influence of response orientation on the presence, strength, and directionality of the effect using cello tones. We predicted that a response orientation aligned vertically or horizontally with the participant would elicit strong congruency effects in the vertical direction, which would be weaker in the horizontal direction.

Experiment 1

In the same way that pitches are universally coded to vertical space (Parise et al., 2014), the pitch height of piano sounds tends to be mapped to horizontal space independent of pitch range (Weis et al., 2016). A likely reason for this is the layout of a piano; on the piano, pitches are arranged in ascending order from left to right. The knowledge of this organization may reinforce the association of low tones with left and high tones with right side responses, even for non-musicians. On the other hand, not all musical instruments' constructions are the same as a piano. For example, on a flute, pitches are arranged in ascending order from right to left. Low tones are played by the right hand and high tones are played by the left hand. This represents a reversal of the mapping found on a piano. In Experiment 1, piano and flute sounds were tested and compared in terms of their influence on the response orientation effect on pitch-space correspondences. We hypothesized that participants would demonstrate larger interaction effects to the task with the piano sounds than with the flute sounds. This would indicate a stronger pitch-space interaction effect due to the combination of the horizontal layout of a piano keyboard, matching with the horizontally oriented response device. We also expected that higher levels of musical training in participants would be associated with stronger timbre-based effects, due to more experience with the sound of a piano tone (as compared with a flute tone).

Method

Participants. The participants of this study were undergraduate students from the University of New Brunswick. All recruitment and testing methods were approved by the Research Ethics Board of the University of New Brunswick. Students were enrolled in an undergraduate psychology course, and they received a bonus mark in their course. We initially tested 36 participants, but due to technical issues or low accuracy rate (accuracy < .40 on a task where chance performance would be .33), we excluded five participants from the analysis. The sample for analysis consisted of 31 participants: 28 female and 3 male, M_{age} = 22.2 years, *SD* = 6.40. There were two participants reported as a left-handed, and twenty-nine participants reported as a right-handed.

Materials. A common approach for determining musical competence is to rely on information about an individual's extent of musical training, but relying on musical training status fails to identify musically untrained individuals with musical skill, as well as those who musically trained with low musical skilled compare to their training (Law & Zentner, 2012). Therefore, every participant completed the Goldsmiths Musical Sophistication Index (Gold-MSI; Müllensiefen et al., 2014), which assessed self-reported musical skills and behaviours.

We used a computer-based task controlled by Neurobehavioral Systems Presentation software (v. 20.0). Dots 1.5^{o} in diameter were presented in a 3x3 grid, with dots spaced 10^{o} apart; white dots (255, 255, 255) and black dots (0, 0, 0) appeared on a grey background (128, 128, 128) (see Figure 1). Participants were asked to identify the relative height of a pitch (low, medium, or high). Each trial included an orthogonally varying combination of visual height (3 levels: low, medium, high), visual azimuth (3 levels: left, centre, or right), pitch (3 levels: low, medium, and high), and timbre (2 levels: piano and flute). Height and azimuth controlled which of the dots in the 3x3 grid turned black in synchrony with the tone. Pitch indicated which of three pitches would be presented: low (*C4*; 261 Hz), medium (*G4*; 392 Hz), or high (*D5*; 587 Hz). Each pitch was 7 semitones apart, and all sounds were presented at 80 dB.SPL, with a sample rate of 44100 Hz (32-bit). Tones were 400 ms long with 10 ms onset and offset ramps. Finally, timbre controlled whether the tone presented would be a piano or flute sound. Piano and flute sounds were sourced from the Freesound database. Responding was controlled by a Cedrus RB-540 button box oriented horizontally in front of the participant.

Procedure. Participants were seated in front of the computer, situated approximately 57 cm from the computer screen. The three tones were played before the task started, and participants were informed that these would be the high, medium, and low tones they would hear during testing. Then they were asked to respond to each trial by pressing one of three buttons on the response pad with three response keys oriented horizontally. They were asked to choose the button correspondent to the height of the pitch they heard, by pressing the button on the left for a low pitch, middle for a medium pitch, and right for a high pitch. Participants were instructed to pay attention to both the dot's location and pitch height, but to respond to the pitch. They were also asked randomly (on average, every five trials) to choose the button correspondent to the location of the dot they see. This ensured that participants were paying attention to both pitch height and visual stimulus characteristics.

There were 54 unique stimulus combinations (3x3x3x2 design as stated above), and nine trials per condition, resulting in 486 trials. Each trial lasted about three seconds, meaning the perceptual task took around 25 minutes. The experimental testing included the Goldsmith-MSI (10 Minutes) and the pitch perception task (25 minutes), for a total of 35 minutes not including participant-timed breaks.

Results

All data for these two experiments are available publicly on the Open Science Framework at: https://osf.io/xuamw/. Scores for the Goldsmith-MSI were calculated as per the instructions for the task, and the mean for the Musical Training sub-score was found to be 23.90 (SD = 11.71), which was similar to the stated norm for the scale which is 26.52 (SD = 11.44; minimum = 7; maximum = 49). Response time (RT) and accuracy were measured for each trial of the pitch perception task. We did not see any difference in the pattern of results from the RT and accuracy, therefore, we calculated the Inverse Efficiency Score (IES) for simplicity of analysis in the same way as was done by Klapman et al. (2020). The IES was calculated by dividing the mean RT by the accuracy rate for each combination of conditions. We calculated a pitch-space congruency effect for each participant for each combination of timbre, effect orientation, and pitch. and then subsequently analyzed by means of a mixed model ANOVA with three within participant factors (Timbre, Effect Orientation, and Pitch), followed by post-hoc tests using Tukey's HSD tests ($p < .05$). The full results of the ANOVA are displayed in Table 1, with pertinent statistics included here.

We found a significant main effect of pitch ($p = .007$, $\eta_p^2 = .152$) which showed that performance was significantly better for high pitches as compared to low pitches, with no significant differences involving the middle pitch. Additionally, we observed a significant interaction between Timbre and Pitch ($p = .044$, $\eta_p^2 = .099$), which was further examined using Tukey's HSD post hoc tests. This test revealed that pitch space interactions were significantly smaller for high flute pitches than for low flute pitches. It is important to note that, given the marginal significance of the timbre x pitch effect ($p = .044$), it is possible that this finding could represent a type I error. In any case, an effect this close to the standard level of statistical significance merits further investigation. However, we can still proceed to analyze and interpret the pattern of results present in the data. Descriptively, it was noted that the pitch-space interactions for piano tones were largely similar across the three pitches, while pitch-space interactions for flute tones varied widely as a function of pitch (See Figure 2). This finding, in combination with the numerically larger pitch space interactions for piano tones compared to flute tones, suggests that piano tones yield a more stable pitch-space interaction effect than do flute tones.

In order to quantify the connection between musical training and pitch-space interactions, correlations were calculated between overall pitch-space interactions for each timbre/effect orientation combination and musical training score. While these correlations did not all reach standard levels of statistical significance, taken together they indicated that pitch-space interactions generally correlated negatively with musical training for piano tones (vertical effect: $r = -.126$, $p = .500$; horizontal effect: $r = -.410$, $p = .022$), but positively correlated for flute tones (vertical effect: $r = .389$, $p = .031$; horizontal effect: $r = .349$, $p = .054$). That is to say, the correlations for piano tones were negative for both effect orientations, but only significant for the horizontal effect, while the correlations for flute tones were both positive, but only significant for the vertical effect.

Discussion

In this first experiment, the roles of piano and flute timbre on the interaction between pitch-space correspondences and response mapping were examined. Participants reported the height of tone that they heard, and a visual cue that was either congruent or incongruent with the tone that presented. The results showed that, numerically, participants showed stronger pitch-space interactions when hearing piano tones rather than flute tones, which is in alignment with our predictions suggesting that the congruent alignment between the layout of a piano keyboard and the response device would promote these interactions. Additionally, correlations between pitch-space interactions for each timbre and response orientation, and musical training, revealed that the effects observed in piano tones were negatively correlated with musical training, while positive correlations were found for flute tones. When participants had greater levels of musical training, they showed smaller pitch-space interactions for piano tones, with the correlation being statistically significant for horizontal effects. These findings are similar to ones observed previously, which found that people with greater amounts of musical training showed smaller pitch-space interactions than non-musicians, likely due to their higher levels of pitch perception ability (Klapman et al., 2020). Since they can determine the pitch of a tone based on sound alone, they were less affected by the visual stimuli; this is true with sine tones, and we have now demonstrated the same effect with piano tones.

The finding was reversed with flute tones, with greater levels of musical training being correlated with larger pitch-space interactions on flute tones (significantly for the vertical effect). Timmers and Li (2016) investigated the influence of instrumental expertise on the horizontal SMARC effect. They compared a group of flutists with a group of pianists and found that musical training, in general, influenced the magnitude of the effect, but it was not the case that flute expertise reduced or reversed the mapping between pitch and horizontal location (Timmers & Li, 2016). Once again, we see that the findings in the literature (as well as the current research) do not always paint a coherent picture of the phenomena around pitch-space interactions, and as such we suggest the need for further investigations in the future.

In Experiment 1, the impact of using piano and flute tones on the effect was tested. These results show that the ROMPR effect is stronger when using piano tones than flute tones, and that this effect exists whether or not one takes into account the musical training levels of participants. Correlations indicated that pitch-space interactions are negatively correlated with musical training for piano tones, but positively correlated for flute tones. Having established these effects, it is interesting to consider how experience with pianos throughout the course of one’s life may lead to this understanding of how pitch and space interact, and that this was not the case for an instrument that non-experts are less likely to have experience with. This brings to mind the findings of Lachmair et al. (2017), who discussed differences between influences that act on us over our lifetime, and those that are based on our current context. To further examine this question, Experiment 2 examined these effects by testing the ROMPR effect in a number of situational contexts.

Experiment 2

Music has a wide array of universal, learned, and situational effects on humans. Evolutionary advantages allow pitches and tones to assist us in locating others and estimating their size without the use of the sight (Grassi et al., 2013; Pisanski et al., 2017; Cattaneo et al., 2018) but can also be attributed to the universal force of gravity aligning us vertically against the horizontal surface of the earth (Lachmair et al., 2017). Although it has been shown that even a limited amount of musical training leaves a lasting impact on humans (Li et al., 2018; Pecci et al., 2016; White-Schwoch et al., 2013), it has also been found that with more extensive musical training comes more automaticity of pitch processing (Lidji et al., 2007). Further emphasizing the deep effects of musical training, a study by Elbert et al. (1995) noted that experienced players of stringed instruments show a larger cortical representation of fretting fingers than in control brains. These researchers hypothesized that due to the superior neuroplasticity one has in young age, duration of practice with one's musical instrument could be a critical factor in this topographic reorganization.

Lachmair and colleagues (2017) investigated the grounded-embodied-situated (GES) framework in the context of experienced cellists. In congruence with the examples listed above, the GES framework illustrates how humans orient themselves in space (groundedness), act and interact based on experience (embodiedness), and are malleable and subject to the influence of their present scenario (situatedness). Lachmair and colleagues illustrated through perceptual tasks prompting the SMARC effect how the general public experiences a grounded perception of musical tones, in that this vertical organization of pitches appears to occur inherently. Cellists, however, additionally experience an embodied and situated experience of tones, in that their observed effects are lessened due to training on instruments on which pitch-space interactions are reversed. This is because on a cello, the performer moves their hand downwards along the strings in order to move the pitch higher.

Utilizing elements of Lachmair et al.'s (2017) design, the current study examines the effect of response pad orientation on the strength of pitch-space correspondences in non-cellists by comparing the strength of the effect between the use of a horizontally-aligned responding condition and a vertically-aligned responding condition. It is important to note that in this instance, the vertical response condition was truly vertical (cf. Bruzzi et al., 2017), whereas in previous research the 'vertical' condition is actually sagittal to the participant (e.g. Rusconi et al., 2006, Klapman et al., 2020). We predicted that response orientation would increase the effects of pitch-space interaction. That is, a horizontally aligned response device will benefit the horizontal correspondence effect, while a vertically aligned device will augment the vertical correspondence effect. Additionally, we intended to further analyze the effect of deeply engrained musical knowledge, skill, and perception on responding by administering the Goldsmith Musical Sophistication Index (Gold-MSI). We predicted that those with higher Gold-MSI scores would demonstrate an attenuated effect, because those with more extensive musical training and abilities may rely less on assisting cues in perceiving musical stimuli (demonstrated via less hindrance due to incongruent cues).

Method

Participants. For Experiment 2, we recruited a total of 42 participants. However, only 35 were used for analysis after removing participants with an accuracy of less than 40%. Of the 35 participants, 28 were female and 32 were right-handed, and they had a mean age of 19.79 (SD 6.22). All participants were recruited from undergraduate psychology courses.

Materials & Procedure. The methodology took the same general format as in Experiment 1. One difference for Experiment 2 was that cello tones were employed, presented at: *C3* (130.81 Hz), *F3* (174.61 Hz), and *A#3* (233.08 Hz), all 400ms in duration. All tones were generated in Logic Pro X using stock cello sounds, were presented at 80 dB SPL, with a sample rate of 44100 Hz (32-bit). Another difference was that participants completed half of their experimental blocks with the response box flat on the table, with the other half completed with the response box propped up in a vertical orientation. In order to maximize the similarity to an actual cello, the buttons were facing away from the participant during the vertical-responding blocks.

Results

Scores were tabulated in the same way as in Experiment 1, and level of musical training (M = 19.16, SD = 9.13) was somewhat lower than the norm, just as it was in Experiment 1. Inverse efficiency scores were calculated. Using a factorial ANOVA, three within participant elements were compared: Response Orientation (a flat (horizontal) response box vs. a vertically-oriented response box), Effect Orientation (horizontal vs. vertical), and Pitch (low, medium, and high), along with a between participant variable of Musical Training.

Full results are displayed in Table 2, with pertinent measures of significance and effect size summarized here. The interaction between Pitch and Musical Training was significant ($p = .026$, $\eta_p^2 = .104$). This interaction was subsumed by the interaction between Response Orientation x Pitch x Musical Training ($p = .043$, $\eta_p^2 = .091$), which was further probed by means of Tukey's HSD ($p < .05$) post hoc tests. While this revealed no significant differences between specific data points, descriptively it was shown that pitch-space interactions were generally high overall under vertical response orientation conditions, while under horizontal response conditions interactions were found to be stronger concomitant with increases in pitch (see Figure 3).

Discussion

Experiment 2 sought to examine the ROMPR effect within a grounded-embodied-situated context (cf. Lachmair et al., 2017). Additionally, levels of musical training were measured and compared with participants' responses to a perceptual task. The main finding from Experiment 2 was the significant interaction between Response Orientation, Pitch, and Musical Training. Examining the main within-participant effects here reveals that under conditions of vertical responding, pitch-space interactions were relatively stable across the three levels of pitch. This is reminiscent of the findings of Klapman et al. (2020), who found that vertical pitch-space interactions were universal, and were reinforced by vertical response devices. However, when the response device was oriented horizontally, we found a descriptively stronger effect for high pitches, when compared to low and medium pitches.

In examining the connection between musical training and pitch-space interactions, there were no statistically significant interactions observed. However, it is of interest to note that higher levels of musical training were accompanied by greater effect magnitudes under instances where the effect and the response orientation were congruent. Additionally, negative correlations were observed for incongruent response-effect orientations. This suggests that those individuals with more musical training showed higher levels of effect when things were as they should be – the response orientation matched with the effect orientation being measured. Previous research concerning the horizontal SMARC effect has found that musical individuals are more frequently found to demonstrate a horizontal association between pitches and space without the need for a reference tone (Hartmann, 2016; Lega et al., 2014; Cho et al., 2012; Nishimura & Yokosawa, 2009; Lidji, et al., 2007). It has been shown that individuals with no prior musical training only strongly demonstrate the horizontal SMARC effect with the assistance of a reference tone and task relevance, while experienced musicians displayed the effect regardless of task relevance and without the presence of a reference tone; otherwise, non-musicians show only weak automatic horizontal organization (Cho et al., 2012; Hartmann, 2017). These findings demonstrate the ingrained and automatic spatial mapping that is tied with years of musical training. In the current study, these findings are limited to non-significant correlations with a level of musical training.

General Discussion

This study examined the roles of different timbres and response orientations on the magnitude of pitch-space interactions. In Experiment 1, the impact of piano and flute tones on the effect was tested. In Experiment 2, the impact of response orientation on the presence, direction, and strength of the effect was tested. Our findings indicate that the horizontal ROMPR effect is stronger for piano tones than for flute tones, and that the ROMPR effect was stronger in true vertical response conditions than in horizontal response conditions. These findings are largely in alignment with previous research, although we did not replicate findings showing that those with musical training are quicker and more accurate in assigning musical stimuli to the theoretically correct spatial alignment, particularly when assisted by congruent response-pad alignment (Lachmair et al., 2018; Lidji et al., 2007). Furthermore, the prominence of heightened performance in the vertically-aligned condition is also in support of previous research, because this alignment tends to be more engrained (even in non-musical individuals), perhaps due to more prevalent and universal physical forces (e.g., gravity; Cattaneo et al., 2018; Lachmair et al., 2018; Pisanski et al., 2017). It is also important to note that the effect sizes observed in this, and most other research on pitch-space interactions, are relatively small, which once again suggests the need for larger participant samples to be drawn. The best way to accomplish this goal may be to plan a multisite research study, as the recruitment of highly trained musicians is necessarily limited at a single site.

There was a difference in findings between Experiment 1, where flute tones showed greater magnitudes of interaction effects for low pitches, and Experiment 2, where high pitches had a greater ROMPR effect than low ones. However, in attempting to understand why this combination of findings has occurred, it is useful to consider the instruments themselves and their melodic range, as well as the specific pitches employed here. The low flute tone in the current experiment was C4 (261 Hz) while the high cello tone was A#3 (233.08 Hz). In absolute terms, these tones are similar to one another, and this may well have contributed to them having similar findings with regard to the magnitude of pitch-space interactions observed. In order to further test this finding, future research should examine specific pitch frequencies presented in numerous timbres in a similar paradigm to the one we employed here.

Although musicians were sought for this study, the limited subject-pool (within a university with no music program) hindered this pursuit, meaning our sample consisted mainly of individuals with low levels of musical training. Given that cello tones were used in the present study, a further examination utilizing both cellists and musicians in addition to non-musicians looking at the effect of the different orientation conditions (horizontal and vertical) on the presence and intensity of the horizontal and vertical effects may be of interest. For example, Timmers and Li (2016) compared a group of flutists with a group of pianists, and they found aninteraction with instrumental expertise was only where participants played on their respective instruments shortly before doing the perceptual judgments test. A comparison of two groups of musicians playing instruments with other opposite tone arrangements (i.e. guitar and piano) would be useful to further test the universality of the effect.

A recent study examining instrumental expertise and timbre on the SMARC effect showed that the vertical SMARC effect was universally observed regardless of tone timbre or expertise (Lega et al., 2020). The horizontal SMARC effect was stronger in pianists than in other musicians and non-musicians. Future research on the ROMPR effect should continue to examine the effects of expertise, ideally seeking out a participant pool consisting of highly trained individuals. It would also be of interest to examine the ways in which different stimulus parameters may modulate the effect – for example, by shifting the pitches or visual locations to be closer to each other (or further away).

Overall, the findings from this study suggest that timbre plays a role in the strength of the ROMPR effect only to the extent that the timbre can be associated with the spatial orientation of the source of the sound. Further research might explore using other ecologically valid sound sources with known spatial orientation. We also add to a mixed literature with regard to pitch-space interactions in general, and as such make clear the need for further study of these effects with a greater number of participants in order to increase statistical power.

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Table 1

Summary of Main Effects from Mixed ANOVA of Inverse Efficiency Score (Exp 1)

Effect	df	*F*	*p*	η_p^2
Timbre	1, 30	2.007	.167	.063
Effect Orientation	1, 30	0.090	.766	.003
Pitch	2, 60	5.389	.007**	.152
Timbre x Effect Orientation	1, 30	2.507	.124	.077
Timbre x Pitch	2, 60	3.282	.044*	.099
Effect Orientation x Pitch	2, 60	0.158	.854	.005
Timbre x Effect Orientation x Pitch	2, 60	0.480	.621	.016

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

Table 2

Summary of Main Effects from Mixed ANOVA of Inverse Efficiency Score (Exp 2)

Effect	df	*F*	*p*	η_p^2
Response Orientation (RO)	1, 33	0.24	.631	.007
RO x Musical Training (MT)	1, 33	0.86	.362	.025
Effect Orientation (EO)	1, 33	0.13	.724	.004
EO x MT	1, 33	0.10	.757	.003
Pitch (P)	2, 66	2.60	.082	.073
P x MT	2, 66	3.84	.026 *	.104
RO x EO	1, 33	0.70	.408	.021
RO x EO x MT	1, 33	1.73	.197	.050
RO x P	2, 66	2.53	.087	.071
RO x P x MT	2, 66	3.30	.043 *	.091
EO x P	2, 66	0.29	.748	.009
EO x P x MT	2, 66	0.98	.379	.029
RO x EO x P	2, 66	0.72	.492	.021
RO x EO x P x MT	2, 66	0.72	.490	.021

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

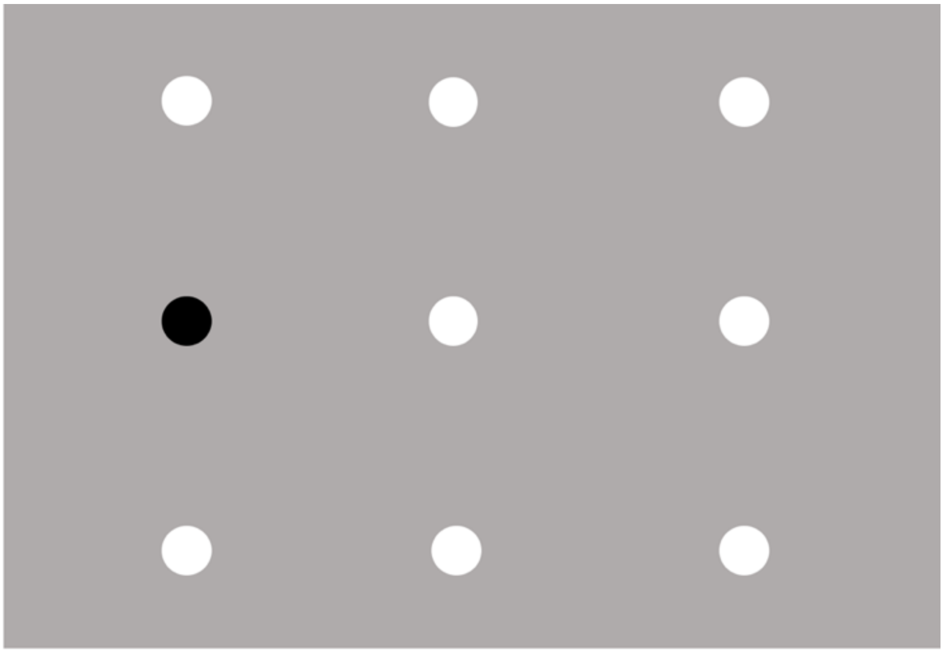

Figure 1. The presentation of the dots used in testing. The dots were 1.5^{o} in diameter and spaced 10 ^{o} apart; white dots (255, 255, 255) and black dots (0, 0, 0) appeared on a grey background (128, 128, 128).

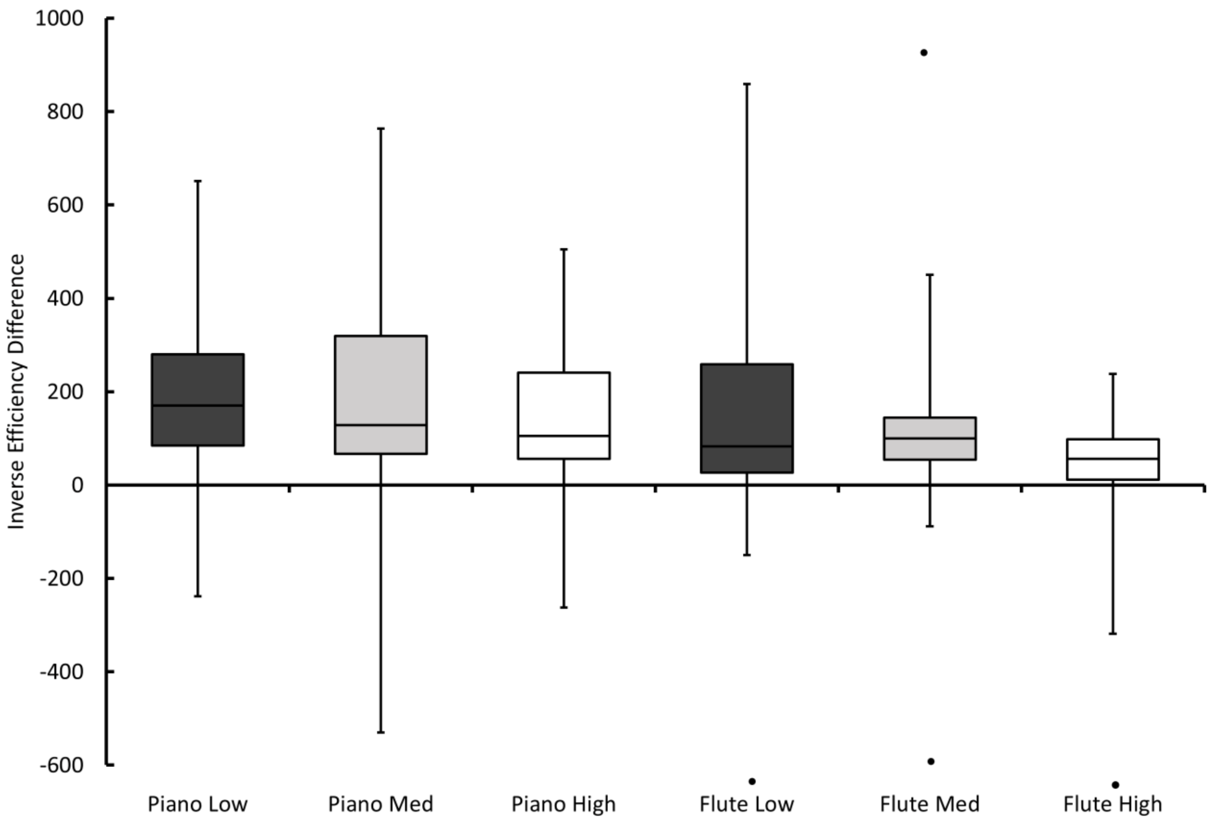

Figure 2. Boxplots of pitch-space interactions (IES) for the significant interaction between timbre (piano; flute) and pitch (low; middle; high) in Experiment 1. Box represents data from the 1st quartile to 3rd quartile, with the median marked in the box. Error bars represent the maximum and minimum values in the data set, with the exception of outliers beyond 3 SD from the mean, which are displayed as dots. Positive values represent an advantage in terms of speed and accuracy for congruent pitch-space pairings, while negative values represent an advantage for incongruent pitch-space pairings.

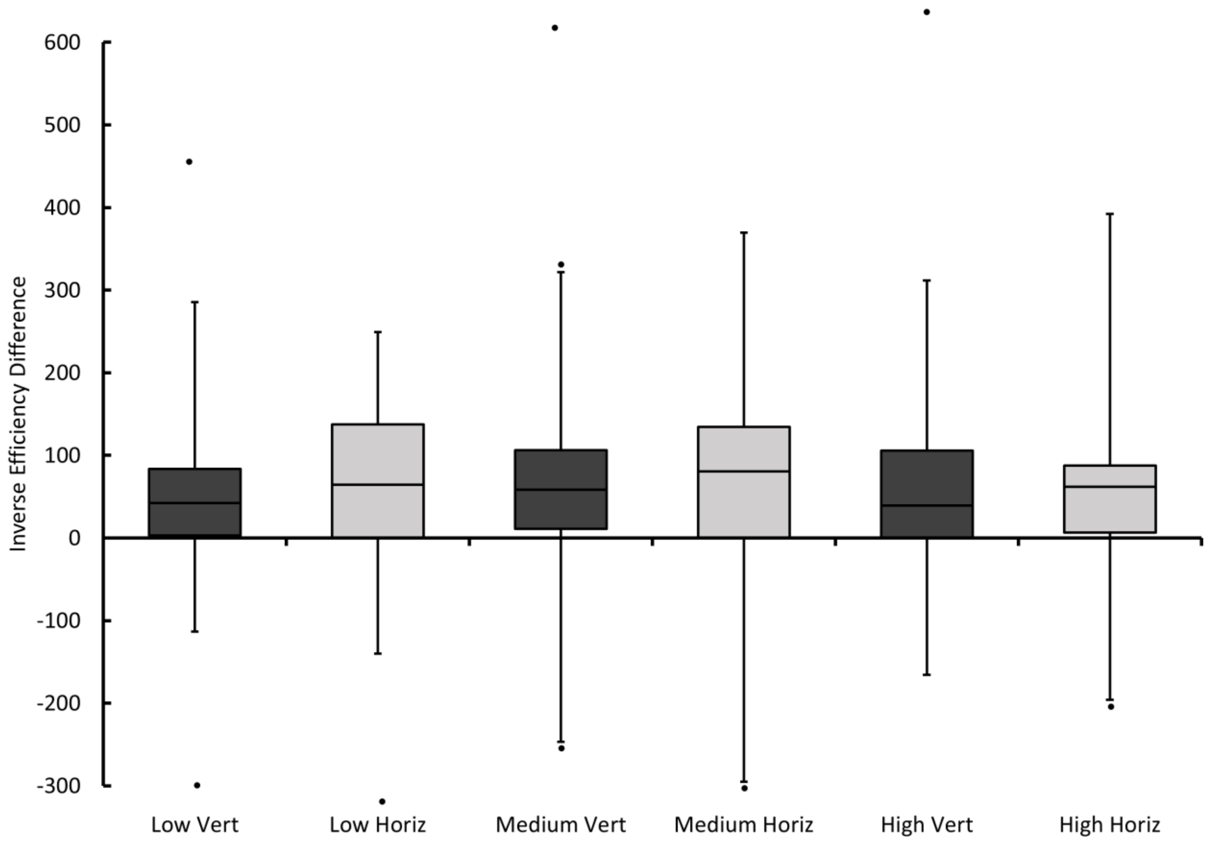

Figure 3. Boxplots of pitch-space interactions (IES) for the significant interaction between response orientation and pitch in Experiment 2. Box represents data from the 1st quartile to 3rd quartile, with the median marked in the box. Error bars represent the maximum and minimum values in the data set, with the exception of outliers beyond 3 SD from the mean, which are displayed as dots. Positive values represent an advantage in terms of speed and accuracy for congruent pitch-space pairings, while negative values represent an advantage for incongruent pitch-space pairings.