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Authors
Kubaszek, Maria
Jastrzebski, Jan
Chuderski, Adam

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Auditory, temporal, and visual sensory discrimination advantage of musicians

Maria Kubaszek
Jan Jastrzębski
Adam Chuderski
Jagiellonian University in Krakow

Abstract

Literature on sensory discrimination suggests that it relies on two separate abilities, one related to processing of auditory-temporal stimuli, and the other involved in processing non-temporal visual stimuli. Musical training is associated with structural and functional adaptations in the brain, which improve sensory processing. However, to date the advantage of musicians was particularly evident in the auditory and temporal tasks (as related with perception of music). This study aimed to investigate potential advantages of musicians not only in the ability to discriminate auditory and temporal stimuli, but also with regard to visual discrimination. As many as nine adaptive stimulus discrimination tasks were administered to 56 musicians and 54 non-musicians, with both groups matched on working memory capacity. The musicians displayed better discrimination scores in each modality, including the visual one. The results support the view of modality-independent perceptual benefits resulting from prolonged musical training.

Keywords: musical training, sensory discrimination

Introduction

Early research on basic perceptual abilities, such as sensory discrimination in visual, auditory, temporal, and haptic modalities, suggested that they depend on some overlapping neural mechanisms (e.g., the speed of neuronal transmission), and therefore can be strongly interrelated (see Jensen, 2002). However, at those early times, existing methodology did not allow for confirming this very claim. In modern times, substantial correlations between various discrimination abilities, as well as links between them and general intelligence, have indeed been shown by multiple studies, encompassing discriminating loudness and color (Deary, Bell, Bell, Campbell, & Fazal, 2004), line length and block weight (Meyer, Hagmann-von Arx, Lemola, & Grob, 2010), as well as sound pitch and visual signal duration (Troche, Wagner, Voelke, Roebers, & Rammsayer, 2014). Recently, Jastrzębski, Kroczek, and Chuderski (2020) comprehensively examined various perceptual skills. The latent variable modeling showed that perceptual abilities can be broken down into two correlated but statistically distinct higher-order factors: the ability to perceive small differences in visual qualities of an object (e.g., its size) and the ability to perceive rapid temporal events (e.g., the order of two blinks). The latter factor was strongly connected with the auditory discrimination (e.g., of pitch and loudness). Both higher-order factors (by Jastrzębski et al. called *featural* and *temporal* discrimination, respectively), strongly correlated with fluid intelligence and memory.

Based on the above findings, the current study investigated the effects of prolonged musical training on featural and temporal discrimination abilities, as well as included auditory discrimination (typically targeted by musical training). The main objective of the study was to examine performance on the battery of sensory discrimination tasks of skilled musicians versus people never trained in music, in order to test whether the presumed advantage of musicians would primarily pertain to the auditory discrimination tasks (and perhaps the temporal discrimination tasks to a lesser extent), supporting a modality-specific nature of musical training, or musicians would outperform non-musicians also in the visual discrimination tasks, supporting a more general account of effects of musical training on perceptual abilities.

Although the visual and auditory discrimination abilities are moderately correlated, yet they differ in the processing time of the stimuli, which suggests why they might be only partially overlapping, and explains why auditory abilities are more closely connected with temporal abilities. Specifically, auditory processing is faster than visual (Shelton & Kumar, 2010), possibly due to the distance the neuronal pulses must travel before they are processed. There is also evidence for the general time perception system operating regardless of the modality of the stimuli – a hypothetical internal clock (Rammsayer, Buttkus, & Altenmüller, 2012) based on neural countdown. The more precise time resolution of the internal clock, the better performance on various temporal discrimination tasks (Rammsayer & Brandler, 2007). However, in timing tasks, auditory stimuli are estimated more accurately than visual stimuli. This phenomenon may be explained by the higher pacemaker pulse frequency in the auditory modality (Wearden, Edwards, Fakhri, & Percival, 1998), as compared to the visual modality. Moreover, the larger amount of information transferred in visual processing and the longer duration of visual information flow may both negatively limit the temporal synchronization in the visual modality, as compared to the auditory modality. Another explanation for a relatively closer relationship of time perception with the auditory modality is their stronger relationship to the motor system, as compared to the visual modality (Repp & Su, 2013).

Why should musical training matter for sensory discrimination? Typically since early childhood, musicians systematically spend hours repeating activities that require motor coordination and continuous, precise monitoring of the sounds produced (Gaser & Schlaug, 2003). While playing an instrument, musicians develop specialized skills, such as the precise time estimation, the ability to quickly process sounds, and the specific motor coordination, often ambidextrous (Moore et al., 2014). During intensive musical training, neural connections develop, especially in the sensorimotor (Gaser & Schlaug, 2003) and auditory cortex (Schneider et al., 2002) and the areas related to multimodal integration (Bangert & Schlaug, 2006). Adaptive neuroplastic changes are visible both on the structural and functional level. Those findings are consistent with the behavioral evidence – musicians obtain higher scores in the auditory processing tasks with both the musical and linguistic stimuli (Bangert et al., 2006; Jakobson, Cuddy, & Kilgour, 2003; Schellenberg & Moreno, 2010). The advantage of musicians was also observed in tasks related to time estimation (Chen, Penhune, & Zatorre, 2008; Rammsay & Altenmuller, 2006).

The debate whether musical training skills generalize to other domains lasts decades. Although in some studies no such transfer had been found (e. g. Carey et al., 2015), in others musicians showed a significant advantage in tasks not strictly connected with the music. Long-term musical training was associated with changes in the structures responsible for time estimation, such as the basal ganglia and additional motor field (Palomar-Garcia et al., 2017; Shih et al., 2009). Changes in these structures can underpin the increased processing speed in musicians, which is important in tasks related with the temporal stimuli (Comstock, Hove & Balasubramaniam, 2018). Playing an instrument had a beneficial effect on the processing speed associated with both the visual and auditory stimuli (Bugos & Mostafa, 2011), yet time accuracy was more pronounced in the auditory tasks (Rammsayer, Buttkus, & Altenmüller, 2012).

However, the structural and functional changes that are visible in musicians' auditory and motor areas, were not found in the visual areas. In line, behavioral studies did not show any advantage of musicians in the visual tasks (Cohen, Evans, Horowitz, & Wolfe, 2011). Based on the meta-analysis carried out by Hetland (2000), the evidence for the transfer of the effects of music training to spatial skills remains largely inconclusive. Despite the fact that multiple non-musical abilities were associated with music training, there is a lack of research that compared the skills of musicians and non-musicians in general visual perception.

The present study aimed to fill the gap by comparing the discrimination ability between musicians and non-musicians across temporal, auditory, and visual perception in a comprehensive way. Increased abilities of musicians only in the temporal and auditory tasks would confirm the division of sensory discrimination into two separate systems (featural and temporal), as claimed by Jastrzębski, Kroczek, and Chuderski (2020). By contrast, a finding that musical training also improves visual discrimination would speak for more general effects of musical training. However, the existing literature suggests that any advantage of musicians in visual discrimination should not be expected.

This led to the formulation of the following two hypotheses:

Hypothesis 1: Musicians, compared to non-musicians, would be more efficient in discriminating stimuli in the auditory modality (loudness and pitch) and more efficient in time discrimination (order of events and interval judgement).

Hypothesis 2: Musicians and non-musicians would achieve the comparable results on the tasks related to non-temporal discrimination of visual stimuli (e.g. size and orientation).

The study

Participants

A total of 110 volunteers (70 females) aged 19 to 30 (mean age = 22, *SD* = 2.7), recruited via ads on popular networking websites, participated in the study. Participants were divided into 2 groups: 56 musicians and 54 non-musicians, based on the survey conducted before the study. In the musical group, 15 participants played on the keyboard instruments, 19 on the string instruments, 7 on the wind instruments and 6 on the percussion instruments. The criterion of qualification was adopted from previous research on musicians (e.g. Koelsch, Schmidt, & Kansok, 2002). Accordingly, musicians were defined as people who had been playing an instrument for at least 10 years. Non-musicians had no musical training nor any contact with playing an instrument. No person reported hearing problems. Vision correction (glasses or lenses) were used if needed. All participants were informed that their data would be anonymous and they could quit the experiment at any moment. The study conformed to the ethical principles of the WMA's Declaration of Helsinki.

Equipment

The study took place in a closed, quiet laboratory room. The procedure was performed on a PC workstation, in the PsychoPy environment. Participants listened to the audio recordings using Sennheiser 407 headphones. The loudness was set to a fixed value for each participant. Visual stimuli were shown on the 17' monitor with the 144 Hz refresh rate and 1920x1080 resolution.

Discrimination tasks

In each of the nine stimulus discrimination tasks, participants were asked to compare the characteristics of two stimuli – either visual or auditory – and to point out one stimulus that had a greater intensity of a given feature, for instance was larger, louder, longer, brighter, appeared first, lasted longer, etc. The responses were given by pressing either the left or right arrow key on the keyboard, depending on whether either the first or second sound was selected, or either the left or right visual stimulus was selected. Each task began with a non-adaptive training that allowed the participants to learn and understand the task instructions. Then, the adaptive staircase procedure kept a fixed response accuracy level of each participant. After three consecutive correct responses, it decreased the perceptual difference between the stimuli, making the task more difficult. After each incorrect response, the procedure increased this difference, making it easier to distinguish between the stimuli. Each task ended after eight changes of the difficulty level, when the accuracy on the task most likely had stabilized (at that point the participants were scoring accuracy of about $M = 0.79$; García-Pérez, 2002). The speed of responding did not matter, although the time to respond was limited (the lack of response within the limit was qualified as an error). The dependent variable in each task comprised the arithmetic mean of the perceptual differences between the two stimuli over the last eight changes of difficulty. The advantage of the adaptive procedure and the expression of results as perceptual differences is that the individual results can be univocally interpreted in terms of the amount of physical units of the difference (e.g., pixels, milliseconds, angles, Hertz, etc.). The procedure allowed the stable performance at the adopted accuracy threshold.

Auditory tasks. In the three tasks, the participants determined which of the two sounds lasted longer, had a higher pitch, and was louder, respectively. In the duration task, the reference duration was 1 second, the initial difference between the sounds was 300 ms, and the step of duration adaptation equaled 30 ms. In the frequency task, the fundamental frequency was 440 Hz, the initial difference was 20 Hz, and the adaptation step equaled 1 Hz. In the loudness task, the initial value was the half of system's sound volume range and it was adapted by 0.05 of that range.

Temporal tasks. In the three tasks, participants had to determine which of the two visual stimuli had appeared on the screen as first. Tasks differed in the stimulus shape – grey squares, circles and triangles were arranged horizontally. The centers of the figures were 4 cm apart. The radius of the circle equaled 1 cm, the side of the square was 2 cm, and the side of an equilateral triangle was also 2 cm. The initial time interval between the onset of successive stimuli was 84 ms. The adaptation step equaled 7 ms (one frame of the screen).

Visual tasks. In the three tasks, participants compared the features of visual non-temporal stimuli. Two grey geometric shapes were displayed horizontally next to each other (shape centers were 5 cm apart) for 1 second. Participants assessed respectively: which of the two squares was brighter, which of the two lines is longer, and which of the two rectangles is more inclined (in relation to the other rectangle). The side of the square in the luminance task was 4 cm, the starting line length in the length task equaled 5 cm, and the parameters of the rectangles in the orientation task were 3 cm x 0.5 cm. The initial differences between the stimuli were: 50% of brightness between the squares, 50 pixels between the lines, and 45º of slope between the rectangles, respectively. The steps equaled 5% of brightness, 5 pixels, and 5º, respectively.

Working memory tasks

To control the influence of working memory (WM) capacity – the key marker of general cognitive aptitude – on the results, a complex span task was administered (see Conway et al., 2005). The sequence of simple geometric shapes, one after another, was presented. The task was to remember and reproduce the order of shapes. Colored bars were displayed after each shape, to interfere with rehearsal and chunking. If the bar had a light color, then the left mouse button had to be pressed, if the bar was dark, then the right button applied. Each shape was displayed for 2 seconds, each bar – until the mouse click occurred. After displaying the sequence of shapes, the participants used the cursor and the matrix of 3 by 3 shapes in order to indicate the particular shapes that had appeared in the sequence, in the order in which they had appeared. The dependent variable equaled the proportion of correctly indicated shapes in all the shapes presented within the task. The procedure was preceded by a training in which the sequence of 3 shapes was displayed.

Due to a procedural error, the musicians received a variant of the test in which they had to memorize the sequences of 4, 6 and 8 shapes, while the control group memorized sequences of 3, 4, 5 and 6 shapes. The task included five trials per each set size. Therefore, the total number of figures to remember was identical in both groups (90), but in the control group the samples were on average smaller. However, there was no difference in WM capacity between the musicians ($M = 0.72$) and non-musicians ($M = 0.71$), $t(108) = 0.61$, $p = 0.545$, and this difference remained non-significant even when only the two matching set sizes (4 & 6 shapes) were taken into account. Therefore, the WM task results suggested that both groups were comparable in terms of general cognitive aptitude, and any differences in sensory discrimination should not be associated with an overall cognitive advantage of the musicians.

Results

A similarity to the normal distribution for each of the task score was confirmed using quantile-quantile plots. The *t*-test for independent groups was performed for each of the nine discrimination tasks to check the statistical significance of differences between the musician and non-musician group. For eight tasks, the musicians needed smaller perceptual differences between stimuli at the same accuracy threshold, (all ps $< .01$). For example, the musicians required the difference smaller by 6 Hz in pitch, 25 ms in sound duration, 2.5% in loudness, 2º in orientation slope, 1.5 pixel in length, and on average 18% in time interval than the non-musicians (all the *t*-tests Tukey corrected, the total $p = .012$). Cohen's d ranged from 0.50 to 1.53, indicating large effect sizes.

A non-significant difference between the groups pertained only to the Brightness task ($p = .353$). However, this task yielded the lowest internal consistency, as estimated by the correlation between the training and the experimental session, $r = 0.31$ (note that calculating internal consistency solely for the adaptive procedure is not possible), while the remaining tasks showed satisfactory consistency (*r*s > 0.5).

Pearson correlations (*r*) among the nine tasks ranged from 0.02 to 0.70. The Circles, Squares, and Triangles tasks intercorrelated strongly (around r = 0.65); the Duration, Frequency, and Loudness tasks intercorrelated moderately (about r = 0.40). There was also a moderate correlation between the Brightness, Length and Orientation tasks (about r = 0.30), except for the Brightness and Length tasks (0.02).

As the tasks within one and the same modality correlated visibly, while the cross-modality correlations were weaker, the number of dependent variables was reduced by means of calculating the principal component for each triad of tasks. The resulting factors reflected auditory (duration, pitch, loudness), visual (length, brightness, orientation), and temporal discrimination (circles, squares, triangles). By accounting only for the variance shared by the tasks, reflected by factors, and excluding the task-specific variance, the factors represented the respective abilities in a more reliable way (Kline, 1998). The factor loadings and the amount of variance explained by a given factor are presented in Table 1. These factors were used for further analysis.

Factor	Amount of variance explained (%)	Task	Factor loading
Auditory	60.32	Duration	0.76
		Pitch	0.79
		Loudness	0.77
Temporal	77.25	Circles	0.90
		Squares	0.86
		Triangles	0.87
Visual	48.23	Brightness	0.55
		Length	0.66
		Orientation	0.84

Table 1: Factor loadings of stimulus discriminations tasks on modality-relevant factors and respective variance explained.

An ANOVA with repeated measures was run, based on the three factors. The Mauchly sphericity test was performed and the assumption of sphericity of the data was fully satisfied (p = 0.235). The difference between the group factor (music training: musicians vs. non-musicians) was tested for three independent variables (three factors: auditory, temporal, visual). The main goal of the analysis was to check whether there was an interaction effect between the group factor and the modality. Such an interaction would indicate that the advantage of the musicians over the non-musicians is greater for some modality, compared to some other modalities. As our factors were expressed in standard deviation units, at the same time ANOVA results allowed the determination of the size of the group effect for each modality.

The ANOVA results indicated that the interaction effect of the group and modality (see Figure 1) only approached the required level of statistical significance, $F(2, 216) = 2.89$, $p = 0.058$. This effect was weak, $\eta_p^2 = 0.026$. The difference between the groups at the factor level equaled 1.32 *SD*, 1.50 *SD*, and 0.94 *SD*, for auditory, temporal, and visual tasks, respectively. Thus, in contrast to our hypothesis, the results suggested that the musicians displayed substantial advantage over the non-musicians also in visual discrimination.

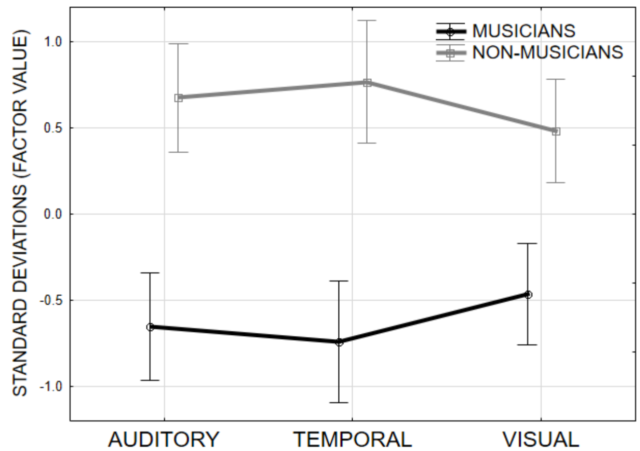

Figure 1: Mean values of the three discrimination factors for musicians vs. non-musicians. Lower values indicate better discrimination. Bars represent standard errors.

The contrast analysis indicated that the group difference for visual factor was significantly smaller than the differences for the other two factors, $F(1, 108) = 5.07$, $p = 0.026$. Thus, there was a small decrement of musicians' advantage in the visual tasks, as compared to the auditory and temporal tasks. However, it should be recognized that all of the differences oscillated around one standard deviation, and all indicated a strong advantage of musicians over non-musicians in terms of discrimination of stimuli in each group of tasks.

In the last analysis, we checked the correlation between the number of years of playing the instrument (a proxy for experience in music training) and the discrimination scores in the group of musicians, computed for each factor separately (see Table 2). There was no statistically significant correlation with training duration for any of the factors. For temporal factor, the effect was marginal. In each case, however, the direction of the correlation was consistent with the predictions, which may indicate that the sample was simply too small to show significant effects.

Variable 1	Variable 2 (factor)	Correlation	*P*
Years of experience	Auditory	-0.18	0.18
	Temporal	-0.25	0.06
	Visual	-0.17	0.22

Table 2: Correlation between the length of musical training (years of playing an instrument) and the individual values of discrimination factors in the group of musicians (N = 56).

Discussion

The results confirmed Hypothesis 1: The musicians required a smaller difference between the auditory stimuli as well as the temporal events to achieve the accuracy threshold of sensory discrimination, as compared to the non-musicians. Therefore, the musicians displayed much more fine-grained perceptual abilities than the people who never played the instrument. The group difference amounted approx. 1.4 standard deviation, which is a large effect. This suggests the strong relationship between music training and the musicians' increased ability to discriminate the auditory and temporal stimuli. Music combines auditory and temporal aspects, so many years of developing music skills seems to relate with the musicians' advantage in these two modalities. Overall, the present results are consistent with existing literature showing the positive impact of music training on sensory discrimination (e.g., Dowling et al., 2008; Rammsay & Altenmuller, 2006; Schellenberg & Moreno, 2010).

Our study also considered the visual discrimination factor. However, in contrast to Hypothesis 2, the difference between the groups also turned out to be statistically significant. The musicians needed smaller differences to discriminate the visual stimuli correctly, although their advantage was slightly smaller than in the other two types of tasks. However, the present study cannot univocally indicate whether this small drop in the musicians' advantage in the visual task resulted from a relatively weaker effect of musical training or from non-optimal design of the Brightness task. Its lower internal consistency might have contributed to potential blurring of some portion of the difference between the groups in the visual factor, which otherwise would have been comparable to the differences in the auditory and temporal modality.

Nevertheless, the large advantage of musicians (almost 1 *SD*) challenges the existing claims that the effects of musical training may be unrelated to visual perception. The present work seems to question the modality-specific view of the impact of musical training solely on the perceptual modules responsible for processing sounds and time events (intervals, rhythms, etc.). By contrast, the work supports the view of general perceptual advantage related with musical training.

Obviously, this study had certain limitations. Firstly, as the Brightness task weakly contributed to the visual factor, this factor primarily depended on the Length and Orientation tasks. It is possible that these two tasks tap not only into visual abilities, but also spatial abilities. Musicians' develop specific note-reading skills, which require understanding the spatial relationships of the notes, what may translate into improved mental rotation (Sluming et al., 2007). Hence, purely visual tasks (e.g., discrimination of colors or small visual features) should be precisely differentiated from the tasks that rely on processing spatial relations.

Secondly, in research related to music training it is a common practice to check the correlation of training duration with the variables of interest. The potential effect of training duration is an important premise allowing to distinguish skill development from any influence of biological predispositions or admission effects (high sensory abilities may determine who becomes a musician and who does not). Therefore, in research on musicians, the number of years spent on music training is an important covariate (Gaser & Schlaug, 2003). On the one hand, the years of playing an instrument did not significantly predict the sensory discrimination scores in the present study, what can be seen as its limitation. On the other hand, there was some trend for discrimination scores to decrease (i.e., improve) over years of training, especially in the case of temporal discrimination. Therefore, the sample studied might simply have been too small to detect actual correlations between training duration and discrimination, but such correlations would be more reliable if the group of musicians was larger than 56 people. Another potential factor attenuating the correlation observed was that only people who had been playing an instrument over ten years were qualified as musicians, what might have restricted the variance in training duration.

In addition, it needs to be acknowledged that there is an evidence indicating that the musicians advantage may be strongly reduced after non-musicians are trained in a specific task for just a few hours. This phenomenon occurs even in case of music-specific tasks, like pitch discrimination (Micheyl, Delhommeau, Perrot, & Oxenham, 2006). Those results raise the question whether the skills observed in musicians origin from long term training.

More generally, it should be kept in mind that the present work did not manipulate explicitly the duration of musical training (as such a manipulation is barely possible and requires years of research), but only constituted a cross-sectional study. Debate connected to the influence of "nature" or "nurture" (genetics or training) on musical skill has heated up in the last decade. In order to distinguish the influence of musical training from natural predispositions, longitudinal studies are needed. Any causal conclusions from the current study should thus be made with great caution. Nevertheless, the study yielded the reliable and – with regard to the visual discrimination tasks – surprising results, which help in understanding the consequences of music training on perception in various modalities.

Conclusion

Supporting one expectation, the advantage of musicians over non-musicians in the auditory and temporal stimulus discrimination was demonstrated. This suggests that musical training can improve perceptual abilities in these two modalities. This result is consistent with existing studies that show such improvements to result from many years of the intense reception and production of music, associated with multiple adaptations at the neuronal and functional level. In contrast to the second expectation, musical training was also related with improvements in visual stimulus discrimination, despite that visual processing is not directly involved in playing the music. This is a novel result, and its origins (e.g., potential dependence on visuospatial abilities) should be investigated in the future studies. Overall, the present study supports the view of general, modality-independent perceptual benefits resulting from musical training.

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