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Musicians react faster and are better multisensory integrators

Simon P. Landry, François Champoux *

Université de Montréal, Faculté de Medicine, École d'orthophonie et d'audiologie, C.P. 6128, Succursale Centre-Ville, Montréal, Québec H3C 3J7, Canada

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ABSTRACT

The results from numerous investigations suggest that musical training might enhance how senses interact. Despite repeated confirmation of anatomical and structural changes in visual, tactile, and auditory regions, significant changes have only been reported in the audiovisual domain and for the detection of audio-tactile incongruencies. In the present study, we aim at testing whether long-term musical training might also enhance other multisensory processes at a behavioural level. An audio-tactile reaction time task was administrated to a group of musicians and non-musicians. We found significantly faster reaction times with musicians for auditory, tactile, and audio-tactile stimulations. Statistical analyses between the combined uni- and multisensory reaction times revealed that musicians possess a statistical advantage when responding to multisensory stimuli compared to non-musicians. These results suggest for the first time that long-term musical training reduces simple non-musical auditory, tactile, and multisensory reaction times. Taken together with the previous results from other sensory modalities, these results strongly point towards musicians being better at integrating the inputs from various senses.

1. Introduction

Musical training is often used as a model for the study of cortical plasticity due to its long-term exposure to and strong association between multiple sensory inputs. Musicians undergo long periods of exposure to synchronous auditory, tactile, motor, visual, and emotional components (Munte, Altenmüller, & Jäncke, 2002; Zimmerman & Lahav, 2012). Long-term experience in such a rich multisensory environment has been demonstrated to lead to significant anatomical and structural changes in visual, tactile, and auditory regions (for a review, see Herholz & Zatorre, 2012); changes that extend beyond musical production. For instance, professional piano plays were found to have significantly less activation than non-musicians in the primary sensory motor cortex, supplementary motor, premotor, and superior parietal areas during complex a non-musical finger movement task (Krings et al., 2000). This reduced activation is understood to reflect the reduced effort required by musicians to produce complex finger movements, an ability honed by the complex movements of piano playing. Long-term exposure to multisensory stimuli from musical production also enhances connectivity between sensory and motor cortices (Luo et al., 2012). This enhanced connectivity from long-term exposure to multisensensory inputs and complex motor production suggests an improved low-level connection between these cortices. The behavioural effects of these important cortical changes on sensory abilities have been widely reported for visual (e.g. Chang et al., 2014; Hughes & Franz, 2007), tactile (e.g. Ragert, Schmidt, Altenmuëller, & Dinse, 2004; Robinson & Kincaid, 2004; Sims, Engel, Hammert, & Elfar, 2015), and auditory processes (Musacchia, Sams, Skoe, & Kraus, 2007; Strait, Kraus, Parbery-Clark, & Ashley, 2010).

Significant behavioural enhancements for the integration of multisensory cues have been reported using complex tasks. Audio-visual benefits from musical training include a narrowing of the integration window for musical stimuli (Lee & Noppeney, 2011) and superior detection of rhythmic asynchrony (Petrini et al., 2009). To date, only one study has examined the behavioural effect of musical training on sound and touch. Kuchenbuch, Paraskevopoulos, Herholz, and Pantev (2014) investigated the effect of musical training on the interaction of musically related auditory and tactile cues by studying musicians' ability to detect incongruent audio-tactile signals. Results from this investigation found that musicians were better at identifying auditory and tactile incongruencies. This strongly suggested that musicians were better at computing information coming from these modalities. The data, however, could not reveal whether musicians were better at integrating congruent audio-tactile information at the behavioural level. Furthermore, to this day, audio-visual and audio-tactile processing capacities in musicians have been exclusively examined using tasks involving music related cues. As such, multi-

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* Corresponding author.
E-mail address: francois.champoux@umontreal.ca (F. Champoux).

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sensory integration capabilities in musicians for non-musical tasks remains unexplored.

The simple reaction time (RT) task is an effective paradigm to study how the brain integrates basic information coming from the various senses. Previous RT investigations with musicians have focused exclusively on the reactivity to unisensory visual (e.g. Anatürk & Jentzsch, 2015; Brochard, Dufour, & Després, 2004; Chang et al., 2014; Hughes & Franz, 2007; Rodrigues, Loureiro, & Caramelli, 2014; Strait et al., 2010; Woelfle & Grahn, 2013) and auditory (Strait et al., 2010; Woelfle & Grahn, 2013) stimuli. To this day, no study has investigated the impact of long-term musical training on simple tactile or multisensory RTs.

Here, we used a simple RT task to test whether musical training enhances audio-tactile integration at a behavioural level. Furthermore, we used statistical models to analyze whether musical training altered the use of sensory information in the context of this RT task.

2. Method

2.1. Participants

Thirty-five participants (16 musicians; 19 controls) enrolled in this experiment. Musicians (10 women, 6 men, M_{age} = 23.8 years, age range: 18–30 years) were recruited from the Université de Montréal Faculty of Music. Control group members (15 women, 4 men, M_{age} = 25.1 years, age range: 19–34 years) were recruited from the Université de Montréal School of Speech Language Pathology and Audiology. Participants were undergraduate students except for seven musicians (1 collegiate, 5 Master's, 1 Ph.D.) and eight control group members (7 Master's, 1 Ph.D.). All participants were self-reported as neurotypical, had normal or corrected-to-normal vision, and had normal auditory thresholds. All participants self-reported as right-handed except for one musicians and one control. All participants completed a self-reported musical training questionnaire (Müllensiefen, Gingras, Musil, & Stewart, 2014) prior to participation to obtain individual musical training scores. The mean control group musical training score was at the 24th percentile (range: 2nd to 58th percentile) while the mean musician group musical training score was at the 91th percentile (range: 76th to 99th percentile). An independent t-test analysis confirmed a statistically significant difference for musical training between groups, $t(33) = -10.998$, $p < 0.001$. Musicians had at least 7 years of formal training on a musical instrument and started playing an instrument between the ages of 3 and 10. The Research Ethics Board of the Université de Montréal approved the study and all the participants provided written informed consent. A sample size of twenty musicians was determined from the median of previous similar RT studies with musicians (Anatürk & Jentzsch, 2015; Brochard et al., 2004; Chang et al., 2014; Hughes & Franz, 2007; Rodrigues et al., 2014; Strait et al., 2010; Woelfle & Grahn, 2013) and was data collection was stopped either once this number of participants was obtained or a significance of $p < 0.02$ was achieved in all three sensory conditions.

2.2. Materials and procedure

A non-musical audio-tactile RT task was used (Nava et al., 2014). Participants were seated comfortably in a quiet well-lit room with their right hand on a standard computer mouse and their left index on a vibrotactile device (Madsen Electronics 03204, Otometrics, Taastrup, Denmark). Participants were instructed to left click on the mouse immediately upon the perception of an auditory, tactile, or simultaneous auditory and tactile stimulation. All stimulations were presented using a custom cognitive evaluation program with PsyScope X software (Cohen, MacWhinney, Flatt, & Provost, 1993). Auditory stimulation consisted of a 50 ms white noise burst presented at 80 dB HL from two speakers (SRS-PC71, Sony, Tokyo, Japan) positioned 60 cm from one another and located 60 cm in front of the participant. Tactile stimulation consisted of a 50 ms vibration of 200 Hz presented by the vibrotactile device. Audio-tactile stimulations were simultaneous presentations of the auditory and tactile stimulation conditions. All participants wore earplugs (Classic Soft, 3M, St. Paul, MN, USA) during the RT task to mask any auditory clues emanating from the vibrotactile device. An ambient white noise from a noise generator was also present to further ensure no auditory clues from the vibrotactile device could be heard. Each of the three conditions was presented 180 times. 36 catch trials in which no stimulus was presented were included to prevent anticipatory responses. A total of 576 stimuli were presented in random order. A random interval of either 1000 ms or 2000 ms was inserted between all stimulations. Responses during catch trials or beyond the inter-presentation interval were considered misses.

2.3. Analysis

RTs were transformed to eliminate outlier data (Whelan, 2008). RTs below 100 ms and above 1000 ms, as well as three standard deviations from each condition's individual mean were eliminated from analysis. Each group's average response time for the three conditions was calculated from this transformed data. A repeated measure test was performed with these average times with stimulation type (auditory, tactile, audio-tactile) as within-subject factor and group (control, musician) as between-subject factor. If a significant effect of condition and group was found, a post-hoc ANOVA (3×2) between stimulation types and group was performed to identify the conditions having significant differences.

Audio-tactile redundancy gains were calculated as the difference between each individual's audio-tactile RT and fastest unisensory RT. A t-test was performed between group mean redundancy gains.

The benefit of bimodal stimulation to RT, known as the redundant signals effect, was calculated using Race Model Inequality (RMI: Raab, 1962). The RMI posits that compared to unimodal stimulation, simultaneously stimulating two modalities increases the likelihood of a more rapid response because both modalities "race" to the behavioural task demand. According to RMI, the likelihood of a faster RT is increased for bimodal conditions since input from both modalities increase the likelihood to produce the single desired behavioural response. Combining RTs for unimodal stimulations and comparing them to bimodal RTs can test this hypothesis. To test for RMI violations, individual RTs for unisensory conditions (auditory and tactile) were combined and organized in ascending order. Individual bimodal stimulation (audio-tactile) was also organized in ascending order. These RTs were then divided in ten bins. Each bin's unisensory RTs were combined and compared to multisensory RTs. This process occurs over ten bins, that is to say by comparing the fastest tenth unimodal and multimodal RTs, the second fastest tenth unimodal and multimodal RTs, and so on. Group means of individual RTs for each bin (unimodal and bimodal) were compared using t-test. At least one statistically significant result represented a multisensory RT that could not be accounted by the combination of unimodal RTs and suggested the presence of a neuronal coactivation process. We tested for violations to the RMI using RMITest software (for an in depth description of the applied algorithm, see Ulrich, Miller, & Schröter, 2007).

Lastly, we further analysed the RT data by performing an analysis on the cumulative distribution function (CDF) using 10 ms time bins (Laurienti, Burdette, Maldjian, & Wallace, 2006). Contrary