Wrist Proprioceptive Assessment in Expert Violin Players

A THESIS
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

Dr. Jürgen Konczak
February 2018

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ACKNOWLEDGEMENTS

The completion of this thesis could not have been possible without the support of many people throughout this process. I would like acknowledge my gratitude to a list of individuals who have left a lasting impression on me and my work.

First and foremost, I cannot thank Dr. Jürgen Konczak enough for all he has done for me here at the University of Minnesota. I sincerely appreciate the guidance, support, knowledge transfer, and encouragement that he has provided for me during my Master's education. It goes without saying, that without you, I could not have succeeded in completing my thesis or achieve the steps necessary for me to continue my career.

I also would like to thank my committee members Dr. Michael Wade and Dr. Paula Ludewig. Their advice, support, and willingness to assist me with my Master's education is tremendously appreciated.

I also could not have done without my fellow lab colleagues in the Human Sensorimotor Control lab for always being there for me in a multitude of ways. Their support, teaching, and friendship are experiences I will never forget, and without them the completion of this thesis would not have been possible.

I also want to thank my participants and research staff, Saurav Dubey, whose assistance and participation made this study possible.

Finally I would like to thank my family for supporting me with my goals. They have always been there for me and encouraged to me to pursue my future; without them I would not have been able to succeed.

DEDICATION

This Master's Thesis is dedicated to my family. My parents have always encouraged me to pursue my goals and did whatever they could to make sure I had the means to achieve them. I also want to thank my siblings for fueling my drive. Whether knowingly, or unknowingly they always provided me with motivation that helped me achieve my goals. Thank you so much for all you have done and know that I could not have done this without you.

ABSTRACT

Proprioceptive afferents from mechanoreceptors in the joints, muscles, tendons and skin give rise to the perception of the movement and the position of the body and its limbs. They provide movement-relevant feedback during the learning of a new skill and are essential for the control of movement. Research has indicated that motor learning not only induces changes in motor function, but also in proprioceptive accuracy. These sensory improvements are associated with short-term plastic changes seen in somatosensory evoked potentials (SEP). To understand, if achieving motor skill expertise is associated with improvements in proprioceptive accuracy, this study assessed wrist proprioceptive acuity in expert violinists and a control group of healthy non-experts. Violin experts use the wrist of their bowing arm to create precise and controlled movements of the violin bow. **Method:** Wrist position sense acuity measures in the flexion/extension plane of ten violin players (M/F = 3/7; 19-58 years old) and eleven non-experts (M/F = 7/4; 18-30 years old) were evaluated using a robotic wrist exoskeleton. Participants judged wrist joint positions using a forced-choice paradigm, which yielded a Just-Noticeable-Difference (JND) threshold as a measure of proprioceptive acuity. SEP was measured as a neural correlate of proprioceptive acuity and to evaluate the early stages of somatosensory processing. **Results**: On average, violin experts reported a lower JND threshold (1.77°) compared to non-experts (1.87°). These results indicated no significant difference in position sense acuity between groups (p = 0.45). However, within the expert violin group, more experienced individuals did show a significant difference (p=0.004) than less experienced individuals. There was also no significant difference in the neurophysiological measures of latency (N30: p=0.69; P20: p= 0 .15), amplitude (N30: p=0.27; P20: p= 0 20) in either component, or peak-to-peak amplitude (p=0.08). **Discussion:** These data indicate that violin players do not show enhanced proprioceptive acuity when compared to controls despite extensive motor practice. However, proprioceptive acuity within the more highly trained and older expert violin group

was significantly higher when compared to experts with less training. This study suggest that increases in wrist proprioceptive acuity depend on a certain level of experience beyond simply mastering of a skill.

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INTRODUCTION

Proprioception is the ability to sense joint position and movement of the body. Proprioception is essential for body awareness and impacts function such as voluntary muscle control, the regulation of muscle tone and postural stability (McCloskey, 1978; Proske et al, 2012; Reimann & Lephart, 2002; Wei et al 1986). Current research has documented motor learning associated changes in sensory systems and networks in the brain. Motor learning induces increases in grey matter density in the motor cortices (primary motor cortex, supplementary motor area, and ventral premotor cortex), but there are also alterations to the grey matter in the somatosensory cortex (Ostry and Gribble, 2016). More practically, evidence suggests that sensory alterations can occur from movement training outside the rigor of a laboratory setting. Previous literature on dependent learning mechanisms indicates that the next movement plan is updated to become more similar to the last experienced movement, if this movement was successful (Yousif et al, 2015). Research has explored the effect of proprioceptive acuity based on skill acquisition and extensive training or use of limbs. In a study on elite soccer players, research found using an active movement assessment through means of a kinesthetic device that elite soccer players have higher JND threshold in their knees compared to healthy controls (Muaidi, Nicholson & Refshauge, 2009). Another study concluded that expert level tennis players have a higher sense of position sense error than amateur tennis players in the knee and hip joint again through an active assessment (Lin et al, 2006). Thus far, previous literature examined use dependence through an athletic lens. However, athletics encompass a wide variety of motor training such as skill acquisition, weight training, and agility training. All of these training methods strengthen the neuromotor connections used to produce movement. Looking to expand this research into non-athletic populations, I sought to examine musicians, who spend the majority of their training movements focusing on specific targets, and evaluate these acute movements as a means of proprioceptive training through position sense acuity.

In the first part of the experiment, I sought to assess position sense acuity in the wrist by comparing the just-noticeable-difference (JND) threshold between expert violin players and non-experts. The JND threshold is defined as the smallest perceived difference between two detectable stimuli (Elangovan, Herrmann & Konczak, 2013). Using a forced-choice paradigm and the wrist robot device, participants were asked to discriminate between two movements presented to them passively by the wrist robot.

The optional additional assessment of SEP evaluation was offered to each participant. This assessment provided information on somatosensory processing in the cortex. Somatosensory Evoked Potentials evaluate conduction of the afferent pathways to the primary somatosensory cortex (Li, Houlden, & Rowed, 1990). SEP is a series of waves that reflect the sequential activation of specific neural structures along the somatosensory pathways (Poornima et al 2013). N30 peak is a negative peak observed at approximately 30 ms after median nerve stimulation, and N30 reflects early processing of proprioceptive information because it can be observed with intramuscular stimulation (Gandevia, BURKE, & MC KEON, 1984). Looking at the peak-to-peak amplitude from P20-N30 evaluates the cortex pathway from the pre-central (motor cortex) to post-central gyrus (somatosensory cortex). These are the same pathways that are activated in voluntary muscle control, such as playing a stringed instrument, and transmit proprioceptive information such as position sense. Previous research has indicated changes in the primary somatosensory cortex after motor training through means of an increase in grey matter (Ostry & Gribble, 2016). By obtaining amplitude and latency measures from SEP, information on the neurophysiological measures of somatosensory processing in expert violinist may show that some neuroplastic changes took place.

The purpose of this study was to evaluate proprioceptive acuity in the wrist of violin experts compared to non-experts. The results of this study should add to the research evaluating proprioceptive acuity measures in movement expert individuals, with the prediction that expert level groups show a lower JND threshold compared to non-experts. This study will also add information on neurophysiological measures of somatosensory processing, a topic not widely evaluated in association with motor performance. A shorter time-to-peak amplitude (latency) and larger peak-to-peak amplitude in expert violinist would indicate long-term neuroplastic changes took place in conjunction with movement expertise.

Specific Aims

1) **Determine, if wrist proprioceptive acuity in expert violin players is improved compared to non-experts.**

Specifically, evaluate wrist position sense in expert string players and healthy controls that do not play a string instrument. Wrist position sense was examined using a patented wrist robot measuring a Just-Noticeable-Difference (JND) threshold. Demonstrating that the position sense JND thresholds of expert violin players are systematically and significantly lower than those of non-expert controls will verify Aim 1.

Hypothesis: Expert violin players will exhibit a significantly lower JND threshold compared to non-experts.

2) **Determine, if markers of early somatosensory processing are different in expert violin players when compared to controls.**

Cortical activity during median nerve stimulation was recorded using 9-channel electroencephalography (EEG) above the contralateral (left) cortex.

Analysis of signals from electrode FC1 (above the wrist/hand area of somatosensory cortex) was used as a measure of somatosensory activation. Showing that skilled violin players have a significantly shorter P20 or N30 time-to-peak latencies, higher amplitude in P20 or N30, and/or higher peak-to-peak amplitude (P20-N30) than the control group, will verify Aim 2.

Hypothesis: Expert violin players will have **a shorter time-to-peak amplitude (latency), higher peak amplitudes, and peak-to-peak** amplitudes in the P20 and N30 component

METHODS

Participants

Ten violin players (M/F = 3/7; 19-58 years old) and eleven non-expert, non-playing healthy controls (M/F = 7/4; 18-30 years old) participated in this study. All eleven of the non-expert participants completed both the proprioceptive acuity assessment and the SEP evaluation, while only six of the ten expert violin players participated in the SEP evaluation (See experimental design). In this experiment, experts were classified as someone who had been playing their violin for approximately of 10 years or more and are currently still playing. Non-experts were classified as participants who are not a member of collegiate sports or other university organizations that require a specialty. The participants were recruited through flyers posted around the University of Minnesota or through emails distributed to local orchestras such as the University of Minnesota's student orchestra, St. Paul Chamber Orchestra, Minnesota's Orchestra and MacPhail Center for Music. Interested individuals contacted the lab for further information and, after agreeing to participate, participants signed a consent form prior to the beginning of the experiment. The University of Minnesota IRB approved all procedures and methods in this study. The Edinburgh Handedness Inventory was used to determine the participant's dominant hand (Oldfield, 1971). Participants that reported a muscular or neurological disorder in the upper body or a recent injury within the past 6 months were excluded.

Table 1:Participant description of both expert violinist and non-experts.

Non-Experts				**Expert Violinists**			
Subject ID	Sex	Handedness	Age	Subject ID	Sex	Handedness	Age
Con_S05	Male	Right	25	V_S06	Female	Right	24
Con_S07	Male	Right	25	V_S15	Female	Right	58
Con_S11	Male	Right	27	V_S16	Female	Right	19
Con_S18	Male	Right	20	V_S17	Male	Right	48
Con_S19	Female	Right	22	V_S26	Male	Right	23
Con_S20	Male	Right	20	V_S27	Female	Right	40
Con_S21	Male	Right	29	V_S28	Female	Right	29
Con_S22	Male	Right	20	V_S29	Male	Right	38
Con_S23	Female	Right	18	V_S30	Female	Right	21
Con_S24	Female	Right	18	V_S31	Female	Right	25
Con_S25	Male	Right	24				

Experimental Design

This study followed a two group by single treatment design. Two assessments were conducted and the following measures were obtained: 1) Just-Noticeable-Difference (JND threshold) measuring position sense acuity in the wrist and 2a) peak-to-peak amplitude and 2b) time-to-peak (latency) of the P20 and N30 peaks. Recruited participants were placed in a group of non-experts or expert violin players. Both groups underwent a proprioceptive acuity assessment via a wrist robot device determining the JND threshold. Upon completion of the proprioceptive assessment, participants were asked, if they wanted to volunteer for a SEP assessment as well. The SEP portion of the test was voluntary and was not required by participants for the completion of this study.

Instrumentation

Assessment of Proprioceptive Acuity

The wrist robot is a device that allows for passive movement in three degrees of freedom (flexion/extension, abduction/adduction, supination/pronation). In this study, the robot used only one of the four brushless DC motors (precision: 0.00018°/step) that allowed passive movement of the wrist in flexion and extension only (± 70° range of motion). Structural blocks were also placed on the robot to prevent any movement in the abduction/adduction plane (See figure 1). A workstation controlled the robotic device by means of an Analog/Digital I/O PCI card (Sensoray, model 626) with four counters reading the end effector positions from the optical encoders embedded in the DC motors. The software environment was based on Real-Time Windows Target™. The wrist robot allows for specific targets to be reached consistently and precisely.

Figure 1. Experimental set up. The participant is seated in a height adjustable chair and the forearm is placed in the platform of the wrist robotic device. The participant then grips the handle and the handle is adjusted to line up the rotation axis of the wrist with the rotation axis of the robot. The wrist robot presented two consecutive wrist positions for the participant to discriminate between.

The SEP evaluation was conducted using ANTneuro eego EEG equipment [64 channel NeuroANT EEG cap] (eemagine Medical Imaging Solutions GmbH Berlin, Germany). A Grass S88 Electrical Nerve/Muscle Stimulator (Grass Technologies, West Warwick, RI) was used to send electrical impulses through a surface electrode placed on top the median nerve, stimulating the Abductor Pollicis Brevis (APB) muscle (Figure 2). Square-wave pulses of 0.2 ms duration was delivered at random time intervals within a range of 1 to 2 seconds at an intensity that elicits thenar muscle contraction and a visible twitch of the thumb. 1500 pulses were delivered at a frequency of 3 Hz.

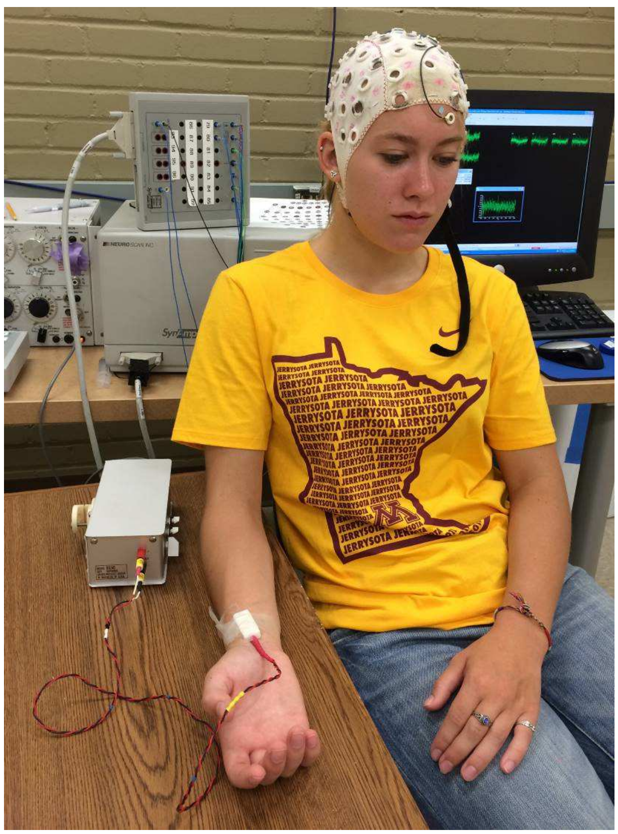

Figure 2. SEP evaluation set up. Participant was seated in a height-adjustable chair with the tested arm rested on the table in comfortable position. EEG was set up first, followed by the stimulation electrode that was secured on the wrist above the median nerve with a hypoallergenic, adhesive medical-grade tape, placed on the dominant wrist.

Procedure

Assessment of Proprioceptive Acuity

Participants began by placing their forearm on the armrest of the wrist robot device. The researcher aligned the wrist joint axes with the joint axes of the robot and set the placement of the chair so that the participant's shoulder and elbow were at a comfortable position. The dominant forearm was secured with velcro straps and the participant wore vision-occluding glasses and headphones producing pink noise to prevent sensory input other than proprioceptive information. Upon verbal confirmation of readiness, the robot passively moved the hand to a reference angle of 15°, back to the starting position, to a deviation angle greater than 15°, and back to starting position. The order of the presentation of the reference angle and the deviation angle were randomized. After the participant had been exposed to both angles, they were asked to indicate, "which movement was larger", meaning further from the starting position of 0°, under a forced-choice paradigm. Their answer was recorded and the PSI method adaptive algorithm presented the next deviation angle based on the answer given. The next angle pair is determined such that if the participant answers the question correctly, the deviation angle will be closer to the reference angle (more difficult) and if they answer incorrectly the difference between the reference angle and the deviation angle will increase (less difficult). After 30 trials, the algorithm converges on an acuity threshold defined as the Just-Noticeable-Difference or JND threshold. Participants underwent 4 familiarity trials prior to testing with large deviations between the two angles: the reference angle of 15° and a deviation angle.

Assessment of Somatosensory Evoked Potentials

After participants completed the proprioceptive assessment, they had the option to volunteer for an SEP evaluation. The subject was seated in the chair comfortably with both forearms supported on the table. The subject wore an EEG cap and conductive gel was placed on the pre-determined channels (Figure 3). A stimulation electrode was applied over the median nerve (cathode proximal) of the dominant hand at the wrist. A mild electrical stimulus was applied to the median nerve using an electrical stimulator. A stimulus threshold was found for each participant, defined as the lowest possible intensity at which muscle contraction of the APB is elicited. This intensity was then set as the intensity of the electrical stimulus. The participant rested in a chair remaining as still as possible for approximately 10 minutes while their thumb was stimulated to twitch.

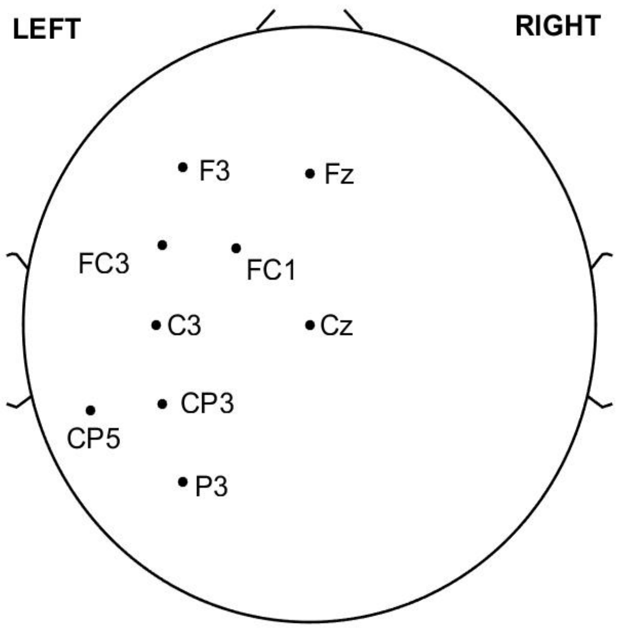

Figure 3. Diagram of the channels used in EEG (Delorme & Makeig, 2004)

Measurements and Analysis

Assessment of Proprioceptive Acuity

Based on each participant's verbal responses, the percentage of correct responses for each trial was computed, and a cumulative log-Weibull function was fitted as a psychometric sensitivity function. From this sensitivity function, the participant's JND threshold was determined the stimulus size at the 75%

correct response level. The 75% level of correctness was chosen because it's halfway between 50% (random guessing) and 100% (always knowing). To understand if there is a difference between expert violin players and non-experts an independent t-test was performed to detect group differences in position sense acuity. The JND threshold was the dependent variable and the two groups served as the independent variables.

Assessment of Somatosensory Evoked Potentials (SEP)

From the nine channels, 1200 samples of EEG data were recorded (see Figure 3). The time-to-peak amplitude (latency) and peak-to-peak amplitude of the P20 and N30 components following median nerve stimulation were determined. N30 is defined as the pole of the neuron and the time that the sample is recorded (i.e. N30 = negative end and 30 refers the 30th millisecond) and similarly P20 is the positive pole at the 20th millisecond. The N30 component has been attributed with tracking the afferent volley from the peripheral sensory nerve potentials to the primary somatosensory cortex (Cebolla & Cheron 2015). The P20 peak is associated with the pathway between the motor and somatosensory cortex except it is the positive pole (Azar, 2016). Information on the peak-to-peak amplitude of the wave as well as the latency from the stimulus to the peak amplitude of the N30 and P20 peak underwent a paired t-test and the means were compared between groups. The latency and amplitude was used as a measure of neuroplastic changes as a result of different levels of movement practice between groups. The alpha level of significance for these measures will be 0.05

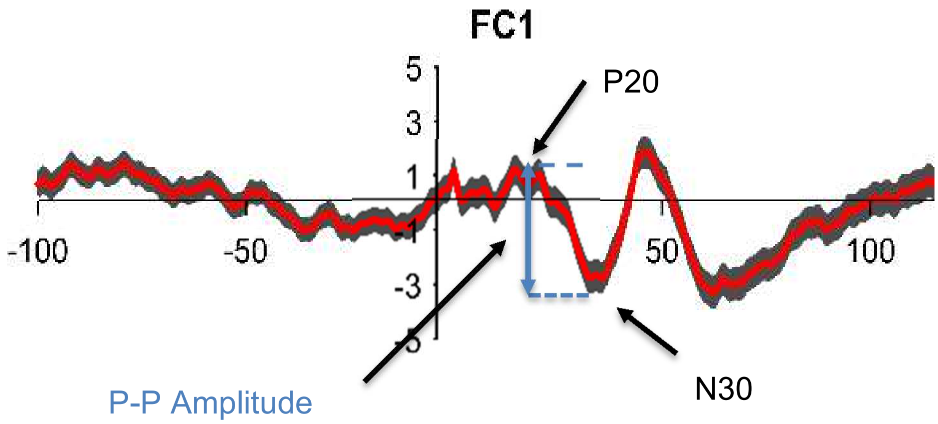

Figure 4. Exemplar EEG data recorded for electrode FC1 for a single participant (Both A and B). P20 indicates the positive maximum at approximately 20 ms latency, while N30 refers to the negative maximum at 30 ms latency. P-P amplitude refers to the difference in voltage between the P20 and the N30 events.

Design and Data Analysis

To understand if there is a difference between expert violin players and non-experts, an independent t-test was performed to detect group differences in position sense acuity. The JND threshold was the dependent variable and group (expert vs. non-expert) served as the independent variable.

The latency and amplitude of the P20 and N30 peaks were measured from the EEG waveforms. A t-test was conducted to examine, significant differences between expert violin players and non-experts in latency, amplitude, and peak-to-peak of the P20 and N30 components. The latency, amplitude are used as a measure of neuroplastic changes as a result of different movement practices between groups. The alpha level of significance for these measures was set to $p = 0.05$.

RESULTS

Assessment of Proprioceptive Acuity

The JND threshold and sensitivity function were computed for each participant. The range of JND thresholds for expert violinist was from 0.78°- 2.69° while the JND threshold for non-experts ranged from 0.61°- 2.91°. The mean JND threshold for violin players is 1.77° with a standard deviation of 0.61 while the non-experts mean JND threshold was 1.88° with a standard deviation of 0.76 (Figure 6). The expert violin group reported a lower JND threshold on average, there is no significant difference between the two groups ($p = 0.070$), rejecting aim 1. However, there was a significant difference ($p=0.004$) within the expert violinist group when comparing the JND threshold and age/level of experience. The violin group was divided into a younger/less experienced group and an older/more experienced group examining the difference in experience of experts. It was determined that the younger/less experienced group (19-25 years) had a higher JND threshold of 2.26° with a standard deviation of 0.25 and the older/more experienced group had a lower threshold of 29-58 is 1.29° with a standard deviation of 0.42 resulting in a significant difference within groups. Slopes of the JND threshold were also compared to look at individual variability between groups, the variability between groups were also insignificant ($p=0.54$).

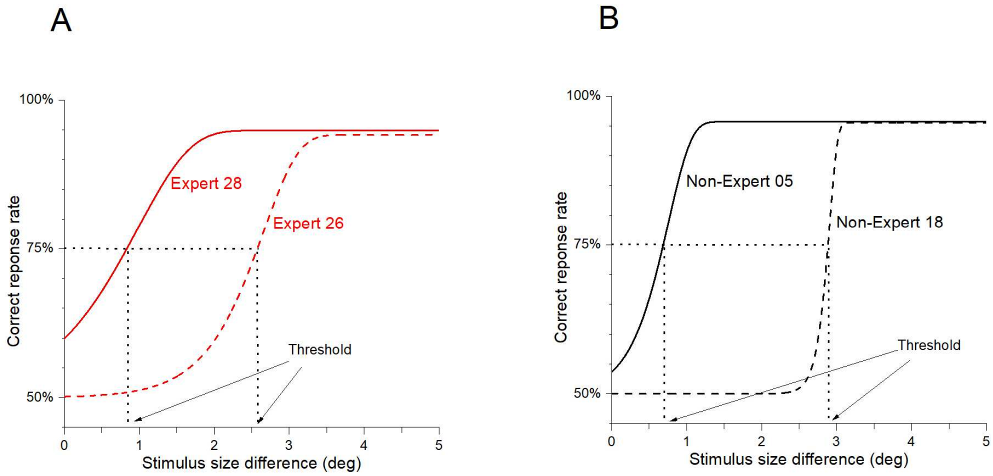

Figure 5. Range of JND thresholds in both groups. Shown are the cumulative log-Weibull sensitivity functions for (A) the expert group (min: 0.78°; max. 2.69°) and (B) the control group (min: 0.61°; max 2.91°).

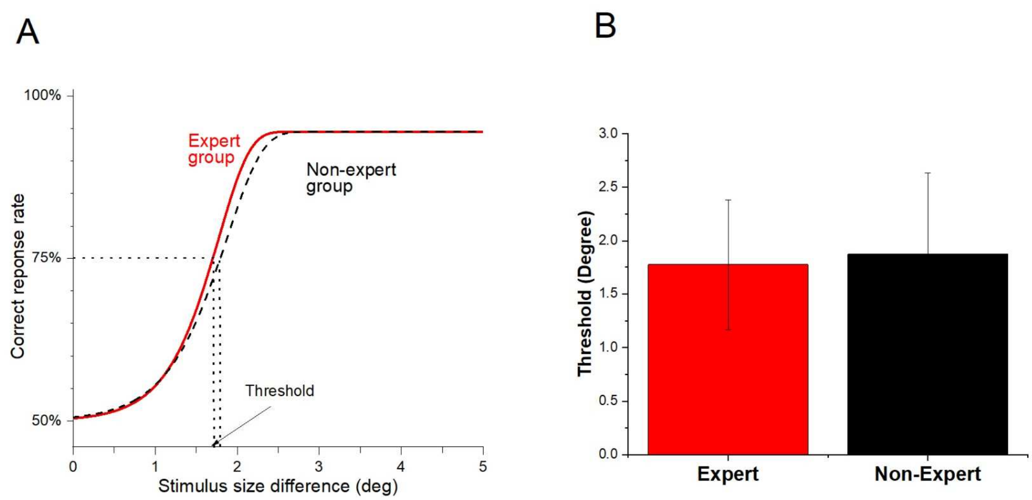

Figure 6. (A) Sensitivity data fitted using a cumulative log-Weibull function between groups. The mean threshold for expert group is 1.77° (SD = 0.61) and the mean threshold for non-experts is 1.88° (SD =0.76). (B) The mean JND threshold and standard deviation for each group indicated no significant differences (p=0.70).

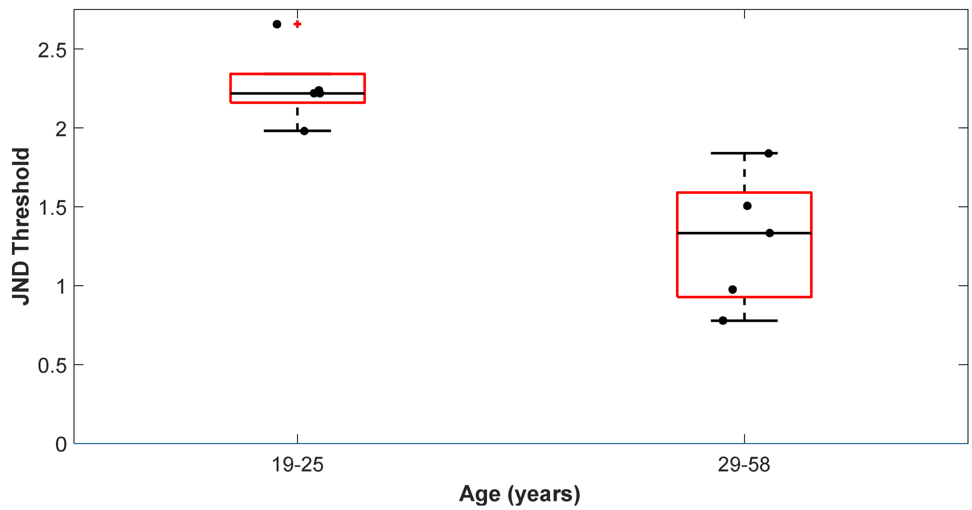

Figure 7: The JND threshold of expert violinist between age groups. The horizontal line within the box indicates the median (2.22 and 1.24), boundaries of the box indicate the 25TH- and 75th -percentile, and the whiskers indicate the highest and lowest values of the results. The mean JND threshold for experts between the age of 19-25 is 2.26° with a standard deviation of 0.25 and for experts between the age of 29-58 is 1.29° with a standard deviation of 0.42 reaching a level of significant difference (p=0.004).

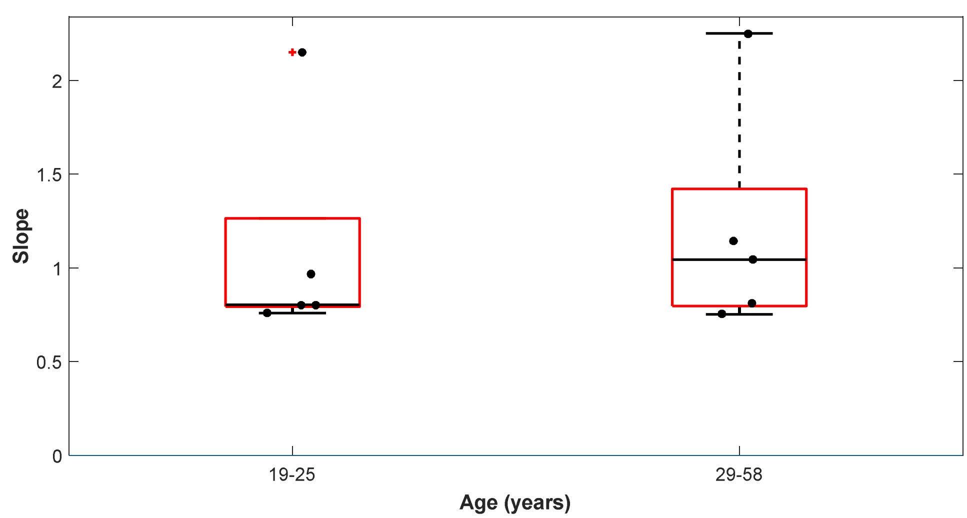

Figure 8: The slope of the sensitivity function for expert violinist between age groups. The horizontal line within the box indicates the median (0.80 and 1.04), boundaries of the box indicate the 25^{TH}- and 75^{th} -percentile, and the whiskers indicate the highest and lowest values of the results. The mean slope of the sensitivity function for experts between the age of 19-25 is 1.10° and a standard

deviation of 0.59 and for experts between the age of 29-58 is 1.20° and a standard deviation of 0.79 ($p=0.54$).

Assessment of Somatosensory Evoked Potentials (SEP)

The latency and amplitude of the N30 and P20 peaks were extrapolated and a t-test was conducted to examine if there are significant differences between expert violin players and non-experts. The peak-to-peak amplitude and standard deviation was computed for both the expert violin players and non-experts ($\mu = -2.73$, SD = 0.569, $p = 0.078$). The latencies of the P20 ($\mu = 19.5$, SD = 2.48, $p = 0.152$) and N30 peak ($\mu = 29.95$, SD = 3.16, $p = 0.689$) and were both not significant. EEG analysis was conducted for nine different channels (Fig. 3) evaluating the P20 and N30 peak amplitudes at each channel (See Table 1). There were no significant differences between expert violin players and non-experts at neither P20 nor N30, rejecting aim 2.

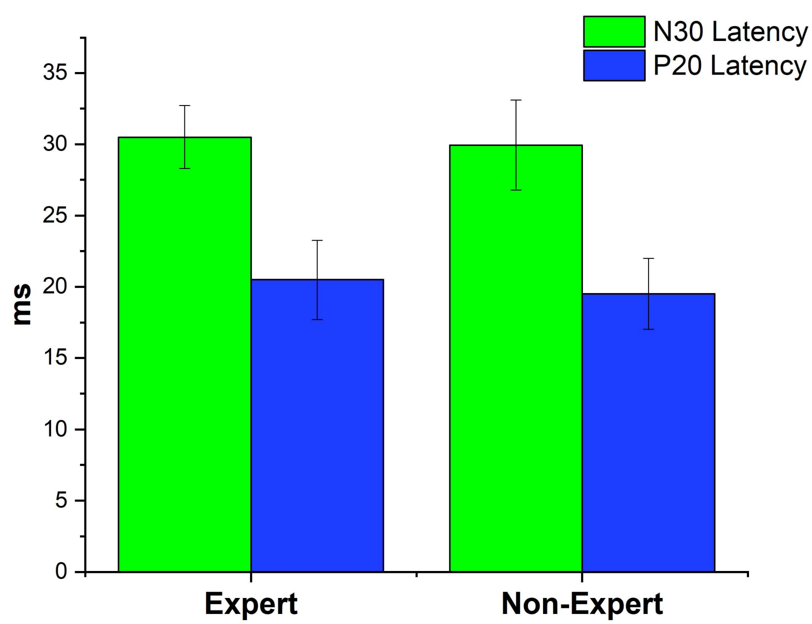

Figure 9. The mean latency and standard deviation of the N30 peak and P20 peak between expert string instrument players (N30: μ =30.5, SD = 2.213 ; P20 μ = 20.5, SD = 2.79) and non-experts (N30: μ = 29.95, SD = 3.157 ; P20 μ = 19.5, SD = 2.483)

Table 2: T-test summary for N30 and P20 peak amplitudes through all channels

	N30				P20			
	Mean Amplitude		Df	P	Mean Amplitude		Df	P
	Non-Expert	Expert			Non-Expert	Expert		
F3	0.023	0.024	6	0.91	0.025	0.018	13	0.59
Fz	0.031	0.028	7	0.73	0.021	0.020	9	0.940.022
FC1	0.022	0.018	5	0.61	0.031	0.014	10	0.37
FC3	0.0168	0.017	7	0.97	0.012	0.013	6	0.662
Cz	0.021	0.014	11	0.18	0.014	0.012	7	0.60
C3	0.0195	0.014	11	0.38	0.012	0.011	6	0.95
P3	0.021	0.011	13	0.10	0.014	0.011	8	0.44
CP3	0.023	0.012	14	0.08	0014	0.011	8	0.46
CP5	0.022	0.012	13	0.1	0.043	0.031	14	0.76

(see figure 3) between groups.

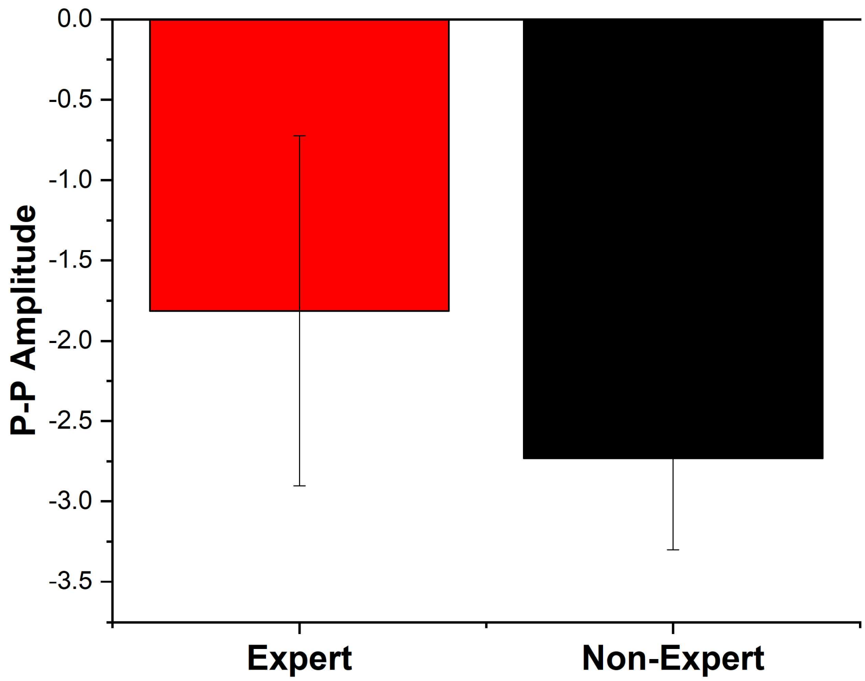

Figure 10: The mean peak-to-peak amplitude and standard deviation of for violin experts (μ = -1.813, SD = 1.09) and non-experts (μ = -2.73, SD = 0.569).

Analysis for Linear Correlation between the Two Evaluations

Figure 11 displays the relationship between the JND threshold and the P-P amplitudes. The linear regression indicated there was a weak positive relationship of r = 0.2338 and an r^2 = 0.06448. This indicates that there is not a significant difference between JND threshold and P-P amplitude suggesting that P-P amplitude is a not a predictor of JND threshold.

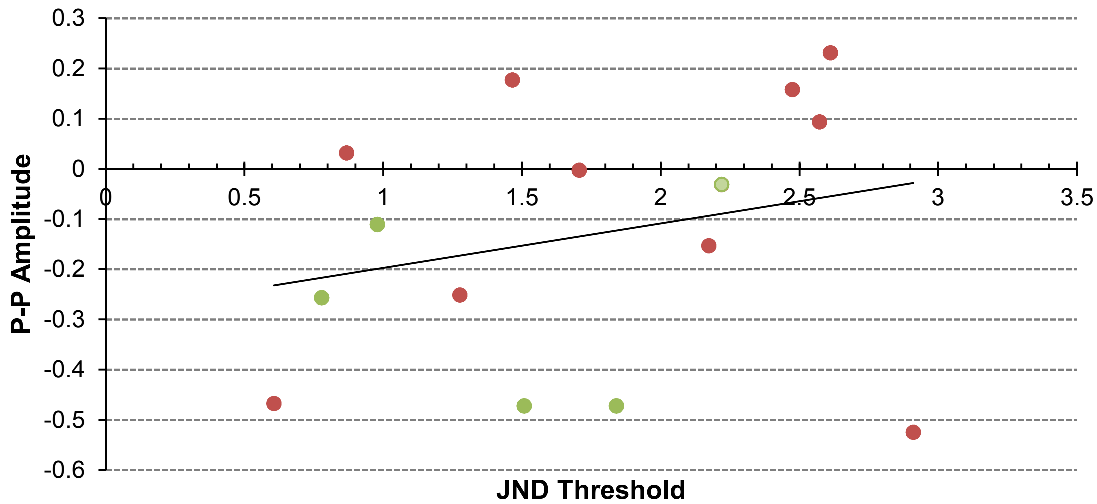

Figure 11. P-P Amplitude regressed on thresholds of both expert level string players and non-experts. The correlation was very weak positive relationship (R^2 = 0.064)

DISCUSSION

The first aim of this study was to examine, if wrist proprioception is activity dependent. Based on the results of this study, it appears that wrist proprioception is not activity dependent in violin players, because there were no significant differences in propriocpetive acuity between violin players and non-experts. However, this is contradictory to previous research reporting that there are significant differences in both soccer players and their knee proprioceptive acuity and tennis players in their hip and knee (Muaidi, Nicholson & Refshauge, 2009; Lin et al., 2006). The study evaluating tennis players, looked at proprioceptive acuity within the tennis group and found significant differences between level of experience (Lin et al., 2006). This study also reported having significant differences in JND threshold within groups albeit the sample size was very small. This could be why other studies have found a significant differences between proprioceptive acuity and this study did not between groups. A power analysis was conducted to determine, if the sample size was to small leading to a difference in this report compared to the previous literature. The power analysis using the means of expert violinist and non-experts agrees with this statement, indicating the number of subject needed to show significance was in the hundreds and a effect size of less than 0.2. A second power analysis was conducted to determine the amount of subjects required to with a meaningful difference in JND thresholds. Based on the within group difference of 0.98 degrees difference within the means, which was statistically significant, the number of subjects required would have only been 17. For that reason, it may not be the amount of subjects, but perhaps the variety in level of experience that resulted in no significance between groups. In this study, to be considered an expert, you must have had 10+ years experience and still practicing the violin. A larger sample with the age, or the level of experience increased to over 20 years experience may have brought about favorable results.

Another reason that no significant difference was found between groups is that perhaps flexion/extension was not the correct movement plane to analyze. The shape of the bridge on a violin indicates that wrist movemenet is closer to abduction/adduction, although the movements are not completely in the orthogonal planes, but actually in-between. Movement in an oblique plane between flexion/extension and abduction/adduction may have resulted in a statistical difference in JND threshold. Movement analysis of violin players also indicates that to help with the contact between the bow and the strings, the movement generation may be derived more from the elbow and shoulder with a slightly more rigid wrist, suggesting that evaluating the elbow joint may have shown more signifcance difference in JND thresholds (Schoonderwaldt, Altenmüller, 2014).

The second aim of this study was to examine SEP's in activity-dependent groups. Based on the results of this study, there was no significant difference in either P20 or N30 in terms of latency, amplitude, or peak-to-peak amplitude between expert violin players and non-experts. This may be because although the expert violin players have a special skill set, they are still healthy human beings, with no neuromuscular disorders or other injuries or abnormalities. Therefore, all of the subjects in this study were considered healthy.

A reduction in SEP amplitudes was reported following visuomotor training in a group of healthy individuals; however, there was no retention and the SEP waveforms returned backed to baseline before the training protocol was completed (Rushton et al., 1981). Therefore, using a different method for evaluating neurophysiological changes such as fMRI may be better suited, because changes in grey matter density has been more consistently supported alternations in long-term plasticity than SEP following movement training.

A correlation analysis was conducted between the JND threshold and P-P amplitude to see if there was any indication of neurophysiological measures that could predict a lower JND threshold. However, this correlation was very weak ($r = 0.2338$) indicating that peak-to-peak amplitude is not a valid predictor of JND threshold. The lack of correlation between the P-P amplitude and JND threshold may be a result of the lack of significant differences between groups in both JND and P-P amplitude. This again is concurrent with the previous literature, if the changes in amplitudes already returned back to baseline post initial movement training as reported by Rushton et al. (1981). There is a possibility that the correlation between JND and P-P amplitudes may have been present initially when the amplitudes may have been significantly different but returned to normal because experts are far beyond initial movement training.

CONCLUSION

In summary, this study examined the relationship between wrist proprioception and activity-dependent use in expert violin players and non-experts. This study showed that there was no significant difference in wrist proprioception in the flexion/extension plane between non-expert and expert violin players. However, this study did show a significant difference in JND threshold and the age/level of experience within expert violinist. This study also demonstrates that there is no significant difference in latency, amplitude, or peak-to-peak amplitude in the N30 and P20 components of an SEP measure.

Evaluating proprioception in the elbow would probably best suit further research with this group. However, due to the wide range of motion required to play the violin, evaluating groups other than violin players with perhaps narrower movement precision requirements may be the best way to further support the existing research that expert or elite groups do have a lower JND threshold. Other studies also reported changes in neural correlates were also more visible through other measures such as fMRI scans. This may be the best way to evaluate neurophysiological measures in the somatosensory cortex.

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