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Altering the Movement: Learning Effects in Beginning and Well-Practiced Flute Players

Andrea Savord
Northern Michigan University, andreasavord@gmail.com

ALTERING THE MOVEMENT: LEARNING EFFECTS IN BEGINNING AND WELL- PRACTICED FLUTE PLAYERS

By

Andrea Savord

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Committee Chair: Dr. Mounia Ziat — Date

____

First Reader: Dr. Sheila Burns — Date

____

Second Reader (if required): Dr. Ilja Frissen — Date

____

Department Head: Dr. Paul Andronis — Date

____

Dr. Brian D. Cherry — Date

Assistant Provost of Graduate Education and Research

ABSTRACT

ALTERING THE MOVEMENT: LEARNING EFFECTS IN BEGINNING AND WELL- PRACTICED FLUTE PLAYERS

By

Andrea Savord

This project examines the extent to which musicians at varying stages of expertise are able to adapt to changes in motor movement (specifically the kinesthetic sense) while playing an instrument. Eight well-practiced and five beginning flute players were tested on playing a major scale on both a modified flute and a traditional flute. The modified flute had altered key positions so that the participants' right hands were on the same side of the instrument as their left hands. The two modified conditions involved either playing the modified flute with the same fingers as one would play on a traditional flute (MOD1) or playing using the same keys one would use (MOD2). The traditional flute was played with standard hand positions and fingerings as a control (CTL). Results show no differences between the two groups, but do reveal differences between the two modified conditions with respect to the control condition across the ten scales.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Going to a concert to watch live music can be a rewarding experience. For audience members this can be impressive and, for those with no musical training, mysterious – how is a single person able to interact with pieces of metal, wood, and string to create the complex sounds we perceive as music? To the musicians themselves, however, the movements and interaction with the instrument seem second-nature. Countless hours of practice and preparation have created a situation where a musician's movements are automatic, fluid, and accurate. The implicit nature of kinesthetic memory allows musicians to perform pieces of music without the effortful processes that were necessary when first learning their instrument. As musicians practice, their skill progresses through the three phases of skill learning (Fitts, 1964; Fitts & Posner, 1967). The first stage requires explicit actions and instruction (such as looking up rhythm patterns or fingerings for various notes), the next is more automatic but still requires instruction, and the final stage is primarily automatic, requiring little or no thought about fingerings or rhythms. The automation of these movements is so strong, it is thought that by the time performers reach the final phase of skill learning, verbalizing actions might not only become more difficult, but could actually impair their performance – a phenomenon known as the "choking" effect (Flegal & Anderson, 2008; Markman, Maddox, & Worthy, 2006; Casteneda & Gray, 2007). This "choking" effect is a result of "over-thinking" one's movements highlights the difficulties involved in altering well- learned motor tasks.

In this study, both well-practiced (eight or more years of experience) and beginning (less than one year of experience) flute players were asked to play a c-major scale on a modified flute in two different conditions. The flute is modified so that the position of the right hand is flipped 180 degrees to be on the same side of the instrument as the left hand (see figure 1). This alteration is to address both the remapping of kinesthetic memory in expert and beginner performers, and how kinesthetic skills evolve from a conscious state to a more unconscious state. It is hypothesized that beginning flute players will initially take less time to play the scale than expert flute players in the modified hand conditions (compared to their respective normal fingering/control conditions) and adapt faster to the modified motor conditions.

Researchers state that it takes ten years or 10,000 hours of focused practice in order to become an expert at a particular skill, including playing music (Simon & Chase, 1973; Ericcson, Krampe, & Tesch-Römer, 1993; Sosniak, 1985). Indeed, deliberate practice is considered to be a large contributor to the acquisition of a skill, arguably surpassing innate talent (Williams & Ericsson, 2005). Deliberate practice involves the mastering of sequential tasks for a given skill through the repetition of actions, along with adjusting performance based on constructive feedback about those actions (Ericsson, 2006). For a musician, this probably means beginning with learning fingerings of notes, then sequentially stringing notes together into major and minor scales or simple melodies, and finally putting that knowledge together for more complex melodies. Ericsson (2006) stresses that to progress through these stages of practice to obtain expertise, people must be both mindful of what they are practicing, as well as able to adjust that practice after receiving constructive feedback.

After a skill has been mastered, the processes become so automated that making intentional modifications to the execution of that skill is difficult (Ericsson, 2006; Hill & Schneider, 2006). It has been shown that it could take up to three times longer to unlearn and relearn a skill that relies on automatic processes than it took to originally develop the skill (Shiffrin & Schneider, 1977; Schneider & Chein, 2003). In a series of three papers, Thorndike and Woodworth (1901a, 1901b, & 1901c) discuss the extent to which different skills would transfer to other skills. Transfer specificity (how similar the learned task is to the novel task) had a great deal of influence over how much of the learned skill would transfer (Thorndike & Woodworth, 1901a).

Several studies have shown that experts respond to changes in a well-learned skill differently than novices. Bardy and Laurent (1998) found that when gymnasts were instructed to perform a somersault with their eyes closed, the expert gymnasts were more susceptible to mistakes than novices. Because the experts relied on visual information more so than beginners, a change to the sensori-motor loop had a greater effect on the experts' performances (O'Regan & Noë, 2001; Ziat, Gapenne, Rouze, & Delwarde, 2006). The experts' automatic processes used visual cues to orient their bodies throughout the somersault, and the removal of those cues forced them to 'unlearn' or relinquish their previous automated habits. The beginners' movements were not yet automatic, giving those gymnasts more conscious control over their movements and allowing them to adapt to the lack of visual input better than the experts.

Another way to examine the differences in motor skills between experts and novices is to alter the actual movements involved in performing the skill. This can be done artificially by using mirrors (as in Ziat, Hayward, Servos, & Ernst, 2011), or physically by changing the position of a limb. Changing the position of a limb has proven to be a useful therapy for musicians with focal dystonia (e.g., Candia et al., 2002). Focal dystonia is a movement disorder inhibiting well-practiced fine motor tasks, such as playing an instrument (Altenmüller and Jabusch, 2009). Currently, it is considered an incurable disease resulting from the overlapping of brain areas representing two separate fingers (Altenmüller & Müller, 2013). However, researchers have found that changing the movement by altering a limb (switching from right-handed to left-handed guitar playing, for example) may provide just enough change to give musicians control over their fine motor movements once more (Candia et al., 2002; McLaughlin, 2013). While focal dystonia only manifests in expert musicians after many hours of repetitive practicing, comparing how healthy beginning and expert musicians adapt to a change in positioning could provide useful information on how kinesthetic memory develops as someone learns to play an instrument, as well as look at how changing a well-learned task affects performance.

It is thought that the different phases of skill learning are correlated with different abilities; cognitive abilities are thought to correlate with initial learning of the task, and perceptual-motor abilities with the final stage of skill learning (Anguera, Reuter-Lorenz, Willingham, & Seidler, 2010; Ericsson et al., 1993; Ackerman, 1988). This is consistent with the first and third stage of Fitts and Posner’s (1967) model, as the beginning of skill learning requires effortful, conscious practice relying heavily on rules that can be verbalized, while by the third stage the movements are unconscious, relying mainly on a musician’s motor memory to carry out a performance. This may also lead to differences in how beginners and expert musicians respond to changes in kinesthetic memory while they are at different stages of the skill-learning process, and could shed light on how people acquire motor skills as well as expand what is known about the different stages of motor skill learning.

Neuroimaging research has also shown evidence of the differences between these phases. The areas of the brain activated during a performance change depending on whether the performer is a beginner or expert. For example, activity in the cerebellum increases as people progress through the stages of skill learning while activity in the motor cortex shrinks and becomes more concise, and activity in the basal ganglia remains strong throughout the skill-learning process (Graybiel, 1998; Graybiel, 2008; Graybiel, 1995; Seidler et al., 2014; Friston, Frith, Passingham, Liddle, & Frackowiak, 1992; Doyon & Benali, 2005; Kleim et al., 1997). Overall, brain activity seems to become more efficient (leading to less activation) as a skill develops (Hill & Schneider, 2006; Seidler et al., 2014).

While there is evidence suggesting that changing a well-learned motor skill can be difficult, this study aims to address how difficult that change is, and whether one type of change is ‘easier’ than another in terms of adaptation. In light of the transfer specificity principles of Thorndike and Woodworth (1901a), two different modified conditions will be tested in the current study: one that is comparatively more similar to typical flute playing, and one that is comparatively less similar. Also, by examining both beginners and experts, this study hopes to give more details about how different stages of the skill learning process is affected by interruptions to that skill. Given the prevalence of movement disorders such as focal dystonia, the ability to ‘unlearn’ and ‘re-learn’ (through remapping techniques) a well-practiced skill is of great importance (Altenmüller & Müller, 2013).

METHODS

Participants

Sixteen participants were recruited from Northern Michigan University and were divided into two group categories: well-practiced and beginners. Three participants were removed from analysis due to data collection errors. Those in the well-practiced category are defined as musicians who have been practicing the flute for at least 8 years; those in the control group are those who are well-practiced on other instruments, but are only beginners (less than one year of experience) on the flute. Eight were well-practiced participants (7 female), and all were right-handed (M=21.0 years, SD=2.33). Five participants were beginners (2 female), and all were right-handed (M=21.6 years, SD=1.52). All participants signed an informed consent sheet before starting the experiment. The experiment was approved by the Institutional Review Board at Northern Michigan University.

Materials

A closed-hole, offset-G C-flute was used for the “normal hand position” condition, and a modified C-flute was used for both of the “modified hand position” conditions (see figures 2 and 3). The participants wore custom-made gloves (see figure 4) that incorporate pressure sensors (FlexiForce, 100lbs) to collect pressure levels and reaction times of finger presses. The sensors are connected to a Phidgets board (Phidgets InterfaceKit 8/8/8), that allows the recording of the data in a program developed specifically for this purpose. Before each experiment, the pressure sensors were calibrated for each participant, as each individual uses different levels of pressure. The audio produced by each participant’s playing was recorded by Audacity to extract the time necessary for participants to play each scale in each condition.

Procedure

After signing the consent form, participants were given a brief questionnaire about their music experience and demographic information. The experimenter then put the gloves on the participant's fingers, ensuring the sensors were comfortable and accurately recording data before starting the calibration phase. This phase consisted of setting up the "on" threshold for each sensor. The participant was asked to press down all the keys while the program recorded the pressure value for each finger. This step was repeated at least four times, until the program could distinguish a key press from a non- key press.

The experimenter then explained the three playing conditions to the participant. For each condition, the participants were instructed to play the C-major scale ten times (ascending and descending) as quickly yet as accurately as possible. In the control condition (CTL), the participant used the normal flute and standard fingering patterns that are well-practiced in flute players. The purpose of the control condition is to test the effect of not only the position of the hands, but also the movement of the fingers on timing and accuracy of movements. The final two conditions used a modified flute that involved turning the right hand 180 degrees, so that it was on the same side of the instrument as the left hand (see figure 5).

In the first modified flute condition (MOD1), participants were asked to use the *same fingers* that would be used to play the scale if using the traditional flute, despite the fact that some fingers were in a different position on the instrument. This condition produces sounds that are inconsistent with the C-major scale because the keys being pressed down are incompatible with those needed to play the scale. In the second modified condition (MOD2), participants were asked to use the *same keys* to play the scale as they would on the traditional flute, despite the fact that the keys were being pressed down by different fingers (see figure 6 for the fingering charts for each condition).

Each participant completed the three conditions, which were counterbalanced so that every possible order of conditions was used at least once. In-between conditions, the gloves were adjusted as necessary to ensure the participants were comfortable and the sensors were still recording data. When participants were finished with all three conditions, they were given a questionnaire (see Appendix C) to describe their experience playing with the modified flute, and were asked to rate the ease of both conditions over time on a 7-point Likert scale.

Data Analysis

The times to play each of the ten scales across the three conditions were extracted from the Audacity recordings for each participant. The learning effect was evaluated by comparing time from the first, fifth, and tenth scales. A three-way mixed ANOVA with the within factors condition (CTL, MOD1, and MOD2) and scale (1, 5, and 10) and between factor group (Beginner and Well-Practiced) was performed to assess changes in time for each scale played for each condition. Greenhouse-Geisser corrections were used when the sphericity assumption was violated. Significance level was set to 0.05 and post-hoc tests were performed using paired-sample t-tests with a Bonferroni correction. Simple effects tests using one-way ANOVAs were conducted when the interaction was significant. A paired-samples t-test was used to evaluate Likert- scale ratings of difficulty for the two modified conditions.

The pressure data consisted of a timestamp (pressure was recorded on average every 0.05 seconds) and the pressure value at that time. The left pinky and right thumb were not required to press any keys and therefore were not included in the analysis. Before analyzing the data using the spectral analysis for time series, we had to clean the data using traditional pre-processing methods such as moving average models to remove the outlying values that consisted of spikes (considered artefacts of sensor movement within the gloves). We then performed a spectral analysis for each finger on the three scales (1, 5, 10) and the three conditions (MOD1, MOD2, and CTL) between the two groups. In total, 24 graphs were compiled (8 fingers x 3 scales) that each contained 6 averaged spectral analyses (2 groups x 3 conditions).

Spectral analysis (SA) is one method of analyzing time and continuous series data that focuses on the frequency of the data rather than time. Based on Fourier Transform, spectral analysis converts the time series by identifying the sine waves that combine to create the time series. These waves are then analyzed in terms of frequency and are spread out over the frequency domain. Any frequency spectrum can be thought of as the amount of variance that contributes to the data at a specific frequency. SA identifies the different frequencies at which the data set oscillates (in cyc/sec) as well as the amplitude of the oscillation (a larger amplitude is thought to indicate a stronger trend than the smaller amplitude). The sharp peaks in SA are frequency components that contribute to the variance of the time series.

RESULTS

Performance Time

The ANOVA did not show any differences in main effects or interactions between the beginners and well-practiced musicians (see Figures 7a and 7b). However, it did reveal a significant main effect of scale (trial), $F(2,22)=49.84$, $p<0.001$, $\eta_p^2=0.82$, power=1.00. Post-hoc tests show that when looking at both beginning and well-practiced participants' data, Scale 1 (M=14.01, SEM=1.48) took more time than both Scale 5 (M=10.36, SEM=1.09) and Scale 10 (M=9.64, SEM=1.08). There were no differences between Scale 5 and Scale 10. The ANOVA also showed a significant main effect of condition, $F(2,22)=11.92$, $p<0.001$, $\eta_p^2=0.52$, power=0.99. Post-hoc tests reveal that CTL (M=7.86, SEM=0.69) took significantly less time than both MOD1 (M=12.0, SEM=1.74) and MOD2 (M=14.16, SEM=1.59). There were no significant differences between MOD1 and MOD2. The scale x condition interaction was also significant, $F(4,44)=6.42$, $p<0.001$, $\eta_p^2=0.37$, power=0.98. This indicates that playing the scales had different effects on participants depending on the condition in which they were playing.

To break down this interaction, we conducted simple effect tests using one-way repeated measures ANOVAs on each subset of the data. The results of the ANOVAs are displayed in Tables 1a and 1b. Within all three conditions, Scale 1 took significantly longer than Scales 5 and 10, with there being no difference between Scales 5 and 10. Within each scale, we see that for Scales 1 and 5, MOD1 and MOD2 both took significantly longer than the CTL condition, without there being any difference between MOD1 and MOD2. For Scale 10, however, the difference between MOD1 and CTL is no longer significant.

Paired-samples t-test did not reveal a significant difference in participants' ratings of MOD1 (M=3.27, SD=1.39) and MOD2 (M=3.53, SD=1.73) difficulty.

Pressure Data – Spectral Analysis

Out of the original 936 files (3 conditions x 3 scales x 13 participants x 8 fingers), only 492 were used for the spectral analysis after artifact rejection. Files were rejected because of insufficient data, failure of the sensors to accurately record data, or due to the amount of noise within a file (frequent, sharp peaks that could not be explained by key presses, etc.). In the following analysis, the first frequency components (C1) were compared within each finger between groups, scales, and conditions. All spectral analysis graphs use the same legend (see Figure 8). For the first finger, data from the table are written out in terms of variance distribution, amplitude, and variance comparison. For the seven subsequent fingers, tables and figures are provided (see Tables 2-9, Figures 9-16) along with a brief discussion of amplitude and variance comparison.

Left Index

Variance distribution

The left index finger of well-practiced and beginner participants show varying trends (see Table 2, Figure 9). For well-practiced participants during CTL, around 74% of the variance of C1 in the S1 time series is described by fluctuations with a period length of around 0.14 Hz; 45.9% of C1 variance in the S5 time series is described by oscillations with a frequency of around 0.17Hz; in C1 of the S10 time series, around 23.4% of the variance is described by fluctuations with a period length of around 0.08Hz. Within MOD1, around 82% of the variance of C1 in the S1 time series is described by variations with a period length of around 0.08Hz; for

C1 in the S5 time series, around 53.6% of the variance is described by oscillations with a period length of around 0.04 Hz; for the time series of S10, around 21.33% of the variance of C1 is described by oscillations with a 0.30Hz period length. For MOD2, around 29.6% of the variance of C1 in the S1 time series is described by fluctuations with a period length of around 0.05 Hz; around 26.9% of the variance of C1 in the S5 time series is described by fluctuations with a period length of around 0.04Hz; around 42.2% of the variance of C1 in the S10 time series is described by fluctuations with a period of around 0.12Hz.

For beginning participants during CTL, around 26.2% of the variance of C1 in the S1 time series is described by fluctuations with a period length of around 0.10Hz; around 59.8% of the variance of C1 in the S5 time series is described by fluctuations with a period length of around 0.12Hz; around 27.3% of the variance of C1 in the S10 time series is described by fluctuations with a period length of around 0.13Hz. During MOD1, around 37.5% of the variance of C1 in the S1 time series is described by fluctuations with a period length of around 0.09Hz; around 27.9% of the variance of C1 in the S5 time series is described by fluctuations with a period length of around 0.11Hz; around 36.4% of the variance of C1 in the S10 time series is described by fluctuations with a period length of around 0.12Hz. Finally, during MOD2 around 32% of the variance of C1 in the S1 time series is described by fluctuations with a period length of around 0.13Hz; around 44.1% of the variance of C1 in the S5 time series is described by fluctuations with a period length of around 0.09Hz; around 53.2% of the variance of C1 in the S10 time series is described by fluctuations with a period length of around 0.11Hz.

Amplitude

When evaluating the amplitude of the peaks (a larger amplitude indicating stronger trend than a smaller amplitude), there is a decrease in overall amplitude from S1 to S10; this suggests that the amount of pressure becomes less consistent (showing weaker trends) over time, but only for the well-practiced participants (Figure 9). The amplitudes for beginner participants appear to be similar across conditions over the three scales. Finally, there do not appear to be any trends between the conditions for either group of participants.

Variance Comparison

When comparing the frequencies between groups, the period length for beginners generally does not show very much fluctuation between scales or conditions (ranging from 0.09Hz to 0.13Hz). Interestingly, this is the same trend seen within amplitude values. Well-practiced players show a larger frequency range, the biggest being within CTL, where period lengths range from 0.08Hz to 0.17Hz. Finally, within the well- practiced group, S10 appears to have the least amount of variation between frequencies compared to S1 and S5 (Table 2a).

Left Thumb

Amplitude

Within this finger, the amplitude of well-practiced players during MOD1 is highest throughout all scales, suggesting that it was pressed more consistently (causing stronger trends) than beginners overall, and more during MOD1 than the other two conditions for well-practiced players (Figure 10). Meanwhile, the amplitude for well-practiced players during MOD2 decreases from S1 to S10, while it remains constant during CTL for all scales. Amplitudes for beginner participants appear to be similar across the conditions and three scales with smaller values relative to well-practiced players.

Variance Comparison

When comparing the frequencies between groups, the period length for beginners seems to show more fluctuation between scales and conditions than well-practiced players (Table 3a, 3b). Looking within the beginner's data, the lowest frequency for both MOD1 and CTL occurs during S1, and the highest frequency during S5. While MOD2 data are not available to compare to these two conditions, this fluctuation in frequencies may indicate that something is happening in the learning process around S5 that is perhaps not yet encountered at the time of S1, and overcome by S10. Looking within the well-practiced players, CTL and MOD1 mimic the beginner's data trends: S1 and S10 both have smaller period lengths than S5. Interestingly, MOD2 shows a different trend, where frequencies increase from S1 to S10. This suggests that for this finger, well-practiced participants may behave similarly during CTL and MOD1, but not MOD2.

Left Middle

Amplitude

Within this finger, the amplitude for well-practiced players decreases from S1 to S10, especially in MOD1 (Figure 11). For beginner players, however, MOD1 and MOD2 amplitudes stay relatively stable, while the amplitude during CTL is significantly larger during S5 than during S1 or S10. In fact, the beginner's CTL S5 has a larger amplitude than even the well-practiced players, while in every other condition and scale the beginners have generally lower amplitudes.

Variance Comparison

When comparing the frequencies between groups, the frequency for beginners seems to show comparable fluctuation between scales and conditions to the well-practiced players, though beginners have higher values overall than the well-practiced. Looking within the beginners' data, S10 appears to have the smallest range of period length between conditions compared to S1 and S5 (Table 4b). There does not appear to be any trends within conditions for beginners. Looking within well-practiced players' data, S10 also appears to have the smallest range of frequencies between conditions compared to S1 and S5. Within conditions, MOD2 has very little fluctuation between frequencies from S1 to S10 compared to CTL and MOD1 (Table 4a).

Left Ring

Amplitude

Within this finger, the amplitudes for both groups across scales and conditions show a lot of fluctuation (Figure 12). Amplitudes for well-practiced increase dramatically during S5 for MOD1 and MOD2, but remain stable across scales during CTL. Beginners also see an increase during S5 for MOD2, but other conditions remain stable across scales. Overall, MOD1 and MOD2 for both groups generally have larger amplitudes than CTL, suggesting that more consistent pressure (causing stronger trends) was used during the modified conditions for both groups.

Variance Comparison

When comparing the frequencies between groups, the frequencies for beginners have a larger range than the well-practiced players (Table 5a and 5b). Overall, both groups tend to have smaller frequencies during S1, suggesting they behave similarly at the beginning of each condition relative to the other scales within that condition.

Within the beginners' data, S1 appears to have the smallest values of period length between conditions compared to S5 and S10. Additionally, MOD2 has a smaller range of frequencies between scales compared to MOD1 and CTL. This suggests that for the left-ring finger, beginners press more consistently during MOD2. Looking within well-practiced players' data, S1 and S10 have relatively small ranges (and values) compared to S5. Of the three conditions, CTL has a larger range with higher values than MOD1 and MOD2. This suggests that well-practiced players press more consistently during MOD1 and MOD2.

Right Index

Amplitude

Within this finger, the amplitudes for both groups across scales and conditions appear to remain relatively stable, except for well-practiced MOD2 (Figure 13). For this condition, well-practiced players have higher amplitudes (and therefore press more) during S1 and S10 than during S5. Amplitudes for beginners are generally lower than amplitudes for well-practiced players and remain around the same amplitude. There does not appear to be a trend between scale, group, or condition.

Variance Comparison

When comparing the frequencies between groups, both generally have a similar range with the exception of the beginner's MOD2 condition. Within the beginners' data, frequency values increase from S1 to S10 across all three conditions (Table 6b). Additionally, the values for CTL and MOD1 are relatively similar across scales, suggesting that beginners have similar key presses during these conditions. MOD2 has a much longer period during S10 than either S1 or S5, and this condition contains both the lowest frequencies and the highest frequencies across the beginners' data. Within well-practiced data, CTL has larger overall values than MOD1 and MOD2 across the three scales (Table 6a). While MOD1 and MOD2 data do not show any particular trend from S1 to S10, CTL shows a smaller frequency for S1 than S5 and S10.

Right Middle

Amplitude

For this finger, amplitudes do not appear to show any particular trend between group, condition, or scale (Figure 14). All amplitudes remain relatively similar across the three scales, with the exception being the beginners' MOD2 data in S5, which is drastically larger than all other groups at that time. Also, aside from the beginners' MOD2 S5 data, well-practiced players generally had higher amplitudes than beginners. The same goes for condition and scale: each graph looks distinctly different from the other two.

Variance Comparison

When comparing the frequencies between groups, the well-practiced group tends to have smaller values for C1 than the beginners, indicating that well-practiced participants' right-middle finger pressed differently than beginners'. The beginner data all follow a similar pattern across the three conditions, where S1 has the smallest period length, followed by S5, with S10 having the longest period length (Table 7b). Additionally, S10 not only has the largest frequency values but also the largest range in values, while S1 has both the smallest frequency values and the smallest range. This suggests that beginners press more consistently across conditions during S1, but conditions become more different from each other through S5 and S10, during which time higher frequencies occur during MOD1 than either CTL or MOD2. Well-practiced players show comparably small variation between the three conditions, with

MOD1 having the largest range compared to CTL and MOD2 (Table 7a). Between scales, no clear pattern emerges from S1 to S10 for well-practiced players, indicating that pressure did not change much over the course of any condition for the right-middle finger.

Right Ring

Amplitude

Within this finger, amplitudes for beginner MOD1 and CTL and well-practiced CTL stay relatively the same across all three scales, but the other conditions fluctuate quite a bit (Figure 15). During S1, well-practiced MOD2 has a much larger amplitude than any other condition, but this goes away for S5 and S10, when the beginner MOD2 condition shows a similar (and much smaller) amplitude. Well-practiced MOD1 has a higher amplitude during S10 than any other conditions, but within the condition has its highest amplitude during S1. Overall, while S1 may show well-practiced participants having a stronger trend (perhaps more consistent key presses) than beginners, there are no general trends across scale, condition, or group.

Variance Comparison

When comparing the variance frequencies between groups, the well-practiced group tends to have smaller values for C1 than the beginners along with a smaller range, indicating that well-practiced participants had less variation in their right-ring finger than beginners across conditions and scales. Within the well-practiced participants, MOD2 had the smallest values and the smallest range of frequency values than both CTL and MOD1 (Table 8a). Within the three scales, however, the frequencies all varied quite a bit between conditions. Among the beginners' data, CTL has larger frequencies along with a larger range of frequencies than MOD1 and MOD2

(Table 8b). This indicates that participants pressed differently during CTL than MOD1 and MOD2, and key presses were less different between S1, S5, and S10 during the modified conditions.

Right Pinky

Amplitude

Overall, there is a decrease in amplitude across scales for all conditions (Figure 16), and in general the well-practiced participants have larger amplitudes than beginners for all conditions. This suggests that there was an overall decrease in the amount of pressure used in the right-pinky, and that beginners tended to use smaller amounts of pressure than the well-practiced participants. Within the well-practiced group, the MOD1 condition has consistently higher amplitudes than the other conditions, followed by MOD2, with CTL having the lowest amplitudes. This suggests that the modified conditions resulted in stronger trends from well-practiced participants. Within the beginners' data, all three conditions seem to have relatively similar pressure for each scale, indicating that beginners had similarly weak trends in all three conditions across all three scales.

Variance Comparison

When looking at the variance for the right pinky between beginners and well-practiced players, the largest frequencies tend to occur during CTL, though the range is much larger within the beginners' CTL data, indicating their key presses were more different between conditions than the well-practiced players. Overall, beginners have longer periods during MOD1 and MOD2 than well-practiced players do. Within the well-practiced participants, frequency values are highest during CTL, and the modified conditions have relatively similar values (Table 9a). This indicates that key presses during the two modified conditions were similar, but both are different from key presses during CTL. Also, the smallest frequencies among the well-practiced data occur during S1 across all three conditions, indicating participants behaved differently over the course of the three scales. Within the beginners' data, smallest frequencies also occur during S1 across the three conditions (Table 9b). Also, the period lengths are less variable amongst the two modified conditions compared to CTL, indicating that key presses were more similar between the three scales during MOD1 and MOD2 than during CTL.

SUMMARY AND CONCLUSIONS

Within these data, both well-practiced and beginning flute players showed a learning effect for all three conditions, with scale times decreasing with each successive repetition of the C-major scale. However, the two modified conditions were not significantly different from each other in terms of scale time, indicating that the difference between the two tasks may not be large enough to differentially affect the kinesthetic memory systems of participants. However, both MOD1 and MOD2 showed a significant difference from CTL for scales 1 and 5, with MOD2 still significant from CTL during scale 10. This suggests that the MOD1 and MOD2 conditions required more cognitive resources than the CTL condition, with MOD2 being more resistant to learning.

The lack of difference between the beginner and well-practiced groups may be due to low sample size, uneven sample sizes, or the nature of the task. Playing a C-major scale may be too simple of a task to reveal any differences in performance that occur as a result of the modifications. Another explanation could be that each group has already had adequate amounts of practice with this task. It is believed that a person's skill for common activities such as driving a car can be brought to an acceptable level of performance after less than 50 hours of practice, and fMRI studies indicate that there is a significant reduction in frontal and parietal lobe activation only one hour into learning a new skill, a trend that is thought to indicate the acquisition of a perceptual-motor skill (Ericsson, 2006; Hill & Schneider, 2006).

Within the pressure data, every finger but the right pinky showed beginner's amplitudes to be the same across conditions and across scales. This indicates that beginner participants used generally the same amount of pressure over time and between conditions. This is contrasted with the well-practiced participants, in which the overall amplitude decreased over time for three fingers (left index, left middle, and right pinky).

Part of skill expertise is being able to recognize meaningful stimuli. In the case of musicians, this could mean being able to identify the fingerings and movements needed to produce a sequence of notes for a given major scale. This is also true for other skills such as chess playing; when beginning and expert chess players are briefly shown a chess board of an in-progress chess game, the experts are better at recalling the positions of various pieces by grouping them into meaningful ‘chunks’ (Chase & Simon, 1973; Miller, 1956). However, if the pieces are arranged randomly on the board, the experts’ advantage is no longer apparent (Chase & Simon, 1973).

The process of being able to effectively identify meaningful stimuli and become an expert at a skill such as music involves searching for a method of deliberate practice that improves performance (Ericsson et al., 1993; Chase & Ericsson, 1981; VanLehn 1995). It is generally thought that skill learning begins with simple actions that are then built upon and refined until the more complex and desired action is achieved (Nelson, 1983; Maloney & Mamassian, 2009). Also, as expertise in a skill develops, performers hone their techniques by optimizing their form and ceasing different movements altogether (Seidler, Benson, Boyden, & Kwak, 2014). This allows performers to ensure their movements are efficient and accurate, and paves the way for further improvement.

This optimization of movement may show itself in the pressure data. For four fingers (left-ring, right-ring, right-pinky, and left-index), well-practiced players showed similar patterns in either amplitude or variance trends for MOD1 and MOD2. For these four fingers plus the left thumb and right index, beginners showed similar patterns (in amplitude or variance trends) for CTL and MOD1. Perhaps in the case of well-practiced musicians, this is because the modified conditions are more different from CTL (well- learned skill) than from each other, in addition to being far less practiced. For beginners, the similarity might be due to the fact that MOD1 and CTL use the same fingers at the same time, and are as a result more similar to each other than the MOD2 condition. Individual differences in both groups, however, still need to be controlled for with a larger sample size to see if these trends persist.

Limitations

Many of the participants (beginners and well-practiced players alike) mentioned how the gloves felt bulky and kept them from knowing whether their fingers were on the correct keys. This not only added an unintended level of complexity to the task they had to perform, but also doubtlessly led to a higher error rate (though none was calculated) than would have occurred without them. In future studies, the sensors could be placed on the instrument itself to avoid these complications and to make the playing seem as realistic as possible.

The fact that no error rate was calculated is another limitation. While it was believed error rate could be assessed from the pressure sensor data, individual playing data from the sensors was not clear enough to assess whether an incorrect key press had been made. Future studies using pressure sensors built into the instrument itself would provide cleaner outputs from which errors can be assessed.

Additionally, the pressure sensor data that was gathered for the spectral analyses could not be looked at from the perspective of cross-spectral analysis. Cross-spectral analysis shows one SA on the x-axis and another on the y-axis, and allows researchers to determine to what extent the trends in one SA explain the variance in trends in the second SA (as opposed to descriptive techniques used in this paper). This would allow for the direct comparison of one SA to another (between beginners and well-practiced players, for example, or scale 1 vs scale 5 within the same group, etc.). Unfortunately, the software used to analyze these data did not provide the option for cross-spectral analysis.

The sample size serves as another limitation; the uneven sample sizes of both groups (8 well-practiced and 5 beginners) makes it difficult to compare the two groups' performances to each other. Also, the relatively low sample size in both groups inflates the impact any outlying data points have on the group averages. Because of this, especially with the SA plots, results may not be as strong as they appear in this study. Finally, the relatively short testing time can be viewed as a limitation, though it may not have a significant negative impact. As mentioned previously, researchers have found differences in brain activation after fewer than 50 hours of practice (Ericsson, 2006; Hill & Schneider, 2006). This efficiency of function is reflected not only in differences in brain activation, but in the muscular system as well, as seen with experienced rowers having significantly less muscle activation than novices (Milton, Solodkin, Hluštík, & Small, 2006; Lay, Sparrow, Hughes, & O'Dwyer, 2002). Because changes in the brain can occur after only one hour, there is hope that this study may hold relevant results since it lasted approximately 1-1.5 hours per participant. A longitudinal or distributed practice design, however, would be more fitting in order to look at how playing behavior during the modified conditions changes long-term.

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APPENDIX A

TABLES

TABLE 1
ANOVA Interaction Breakdown

Table 1a. Shows One-Way ANOVA results for the factor condition. Only significant differences are reported.

Scale		
Factor	F(2,24), p	Significant Pairwise (p<0.05)
MOD1	22.94, 0.001	Scale 1 vs Scale 5 Scale 1 vs Scale 10
MOD2	32.58, 0.001	Scale 1 vs Scale 5 Scale 1 vs Scale 10
CTL	11.80, 0.001	Scale 1 vs Scale 5 Scale 1 vs Scale 10

Table 1b. Shows One-Way ANOVA results for the factor scale. Only significant differences are reported.

Condition		
Factor	F(2,24), p	Significant Pairwise (p<0.05)
Scale 1	16.64, 0.001	CTL vs MOD1 CTL vs MOD2
Scale 5	15.94, 0.001	CTL vs MOD1 CTL vs MOD2
Scale 10	6.57, 0.005	CTL vs MOD2

TABLE 2
Spectral Analysis for LI

Table 2. Spectral analysis data for the left-index finger of well-practiced (a) and beginner (b) participants. For each component, top number represents frequency (f) of the peak (cycles/second), and bottom numbers represent variance fraction (%), variance (F), and standard deviation (SD), respectively. For each scale, component that contributes most to the variance is shaded.

			Well-Practiced (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
LI	CTL	1	0.14 74, 7248, 85.13	0.36 2.65, 259.4, 16.11	N/A
		5	0.17 45.9, 1229, 35.06	0.36 10.09, 270.3, 16.44	0.61 7.161, 191.8, 13.85
		10	0.08 23.42, 444.2, 21.08	0.31 5.83, 110.6, 10.52	N/A
	MOD1	1	0.08 82.04, 3296, 57.41	N/A	N/A
		5	0.04 53.55, 2626, 51.25	0.11 9.11, 446.6, 21.13	0.33 5.78, 283.5, 16.84
		10	0.10 21.33, 635.4, 25.21	0.3 42.12, 1255, 35.42	N/A
	MOD2	1	0.05 29.58, 6764, 82.24	0.25 26.25, 6002, 77.47	0.51 23.62, 5401, 73.49
		5	0.04 26.88, 1517, 38.95	0.11 9.02, 508.9, 22.56	0.26 8.04, 453.6, 21.3
		10	0.12 42.22, 1704, 41.27	0.29 8.04, 324.5, 18.01	0.4 10.68, 431, 20.76

(a)

			Beginner (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
LI	CTL	1	0.10 26.19, 1113, 33.36	0.30 16.98, 721.5, 26.86	N/A
		5	0.12 59.87, 3042, 55.16	0.59 13.45, 683.3, 26.14	N/A
		10	0.13 27.27, 215.5, 14.68	0.83 14.64, 115.7, 10.76	1.11 21.79, 172.2, 13.12
	MOD1	1	0.09 37.52, 1132, 33.64	0.55 12.66, 381.9, 19.54	N/A
		5	0.11 27.92, 670.5, 25.89	0.54 20.47, 490.7, 22.15	N/A
		10	0.12 36.43, 425.3, 20.62	0.63 31.86, 372, 19.29	1.12 10.24, 119.5, 10.93
	MOD2	1	0.13 32.01, 629.3, 25.09	0.61 30.17, 593.1, 24.35	N/A
		5	0.09 44.07, 821.1, 28.66	0.46 18.04, 336.2, 18.34	1.01 19.87, 370.2, 19.24
		10	0.11 53.19, 2012, 44.85	0.43 7.527, 284.7, 16.87	N/A

(b)

TABLE 3
Spectral Analysis for LT

Table 3. Spectral analysis data for the left thumb of well-practiced (a) and beginner (b) participants. For each component, top number represents frequency (f) of the peak (cycles/second), and bottom numbers represent variance fraction (%), variance (F), and standard deviation (SD), respectively. For each scale, component that contributes most to the variance is shaded.

			Well-Practiced (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
LT	CTL	1	0.14 84.52, 9064, 95.21	N/A	N/A
		5	0.18 92.03, 24050, 155.1	N/A	N/A
		10	0.08 70.06, 27240, 165.1	0.39 18.13, 7048, 83.95	N/A
	MOD1	1	0.03 82.33, 80100, 283	N/A	N/A
		5	0.11 87.83, 210000, 458.3	N/A	N/A
		10	0.07 93.23, 97850, 312.8	N/A	N/A
	MOD2	1	0.07 83.35, 65880, 256.7	N/A	N/A
		5	0.09 47.21, 15050, 122.7	0.23 11.4, 3636, 60.3	N/A
		10	0.12 52.66, 9320, 96.54	0.23 8.99, 1591, 39.89	0.46 10.93, 1934, 43.98

(a)

			Beginner (f, %, F, SD)		
FINGER	CONDTION	SCALE	**Component 1**	**Component 2**	**Component 3**
LT	CTL	1	0.10 76.63, 8168, 90.38	N/A	N/A
		5	0.38 80.88, 1167, 34.16	N/A	N/A
		10	0.28 22.94, 330, 18.17	0.70 30.08, 432.8, 20.8	1.41 9.794, 140.9, 11.87
	MOD1	1	0.09 60.74, 8200, 90.56	0.43 11.48, 1549, 39.36	N/A
		5	0.32 75.77, 820.6, 28.65	N/A	N/A
		10	0.15 44.57, 192.9, 13.89	N/A	N/A
	MOD2	1	--	--	--
		5	--	--	--
		10	--	--	--

(b)

TABLE 4
Spectral Analysis for LM

Table 4. Spectral analysis data for the left-middle finger of well-practiced (a) and beginner (b) participants. For each component, top number represents frequency (f) of the peak (cycles/second), and bottom numbers represent variance fraction (%), variance (F), and standard deviation (SD), respectively. For each scale, component that contributes most to the variance is shaded.

			Well-Practiced (f, %, F, SD)		
FINGER	CONDTION	SCALE	**Component 1**	**Component 2**	**Component 3**
LM	CTL	1	0.14 52.12, 4797, 69.26	0.43 17.88, 1646, 40.57	N/A
		5	0.17 30.67, 1645, 40.56	N/A	N/A
		10	0.08 17.99, 3285, 57.32	0.23 41.19, 7652, 87.47	0.47 12.81, 2338, 48.35
	MOD1	1	0.12 66.97, 14250, 119.4	0.28 5.074, 1080, 32.86	0.37 9.309, 1981, 44.51
		5	0.11 49.31, 11640, 107.9	N/A	N/A
		10	0.03 30.76, 2552, 50.52	0.12 29.46, 2445, 49.44	0.28 6.91, 573.8, 23.95
	MOD2	1	0.01 81.44, 72750, 269.7	0.25 6.851, 6120, 78.23	N/A
		5	0.04 37.63, 6540, 80.87	0.27 19.09, 3318, 57.6	N/A
		10	0.02 26.39, 3824, 61.84	0.15 15.38, 2229, 47.21	N/A

(a)

			Beginner (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
LM	CTL	1	0.25 51.35, 8134, 90.19	0.55 10.02, 1587, 39.84	0.91 6.522, 1033, 32.14
		5	0.12 88.76, 119900, 346.2	N/A	N/A
		10	0.28 46.47, 10040, 100.2	0.69 16.98, 3667, 60.56	0.97 5.25, 1134, 33.68
	MOD1	1	0.09 56.8, 1334, 36.52	0.43 7.767, 182.4, 13.51	N/A
		5	0.21 70.84, 1890, 43.48	N/A	N/A
		10	0.25 62.78, 1943, 44.08	N/A	N/A
	MOD2	1	0.13 73.22, 1640, 40.49	N/A	N/A
		5	0.18 78.62, 2708, 52.04	N/A	N/A
		10	0.27 30.27, 2079, 45.6	0.54 8.73, 599.2, 24.48	N/A

TABLE 5
Spectral Analysis for LR

Table 5. Spectral analysis data for the left-ring finger of well-practiced (a) and beginner (b) participants. For each component, top number represents frequency (f) of the peak (cycles/second), and bottom numbers represent variance fraction (%), variance (F), and standard deviation (SD), respectively. For each scale, component that contributes most to the variance is shaded.

			Well-Practiced (f, %, F, SD)		
FINGER	CONDTION	SCALE	**Component 1**	**Component 2**	**Component 3**
LR	CTL	1	0.07 67.8, 12910, 113.6	0.21 8.27, 1575, 39.69	N/A
		5	0.13 64.27, 10810, 104	N/A	N/A
		10	0.08 79.97, 12410, 111.4	N/A	N/A
	MOD1	1	0.03 56.94, 21980, 148.2	0.15 14.29, 5517, 74.28	N/A
		5	0.07 86.21, 120000, 346.5	N/A	N/A
		10	0.03 35.23, 11710, 108.2	0.09 5.512, 1833, 42.18	0.26 16.57, 5508, 74.22
	MOD2	1	0.07 80.56, 22820, 151	N/A	N/A
		5	0.04 43.28, 42390, 205.9	0.12 9.531, 9334, 96.61	N/A
		10	0.07 22.63, 12070, 109.9	0.15 9.8, 5227, 72.3	N/A

(a)

			Beginner (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
LR	CTL	1	0.1 42.54, 23310, 152.7	N/A	N/A
		5	0.12 20.39, 2006, 44.79	0.35 35.79, 3521, 59.34	0.83 7.412, 729.2, 27
		10	0.28 81.49, 3838, 61.96	N/A	N/A
	MOD1	1	0.09 73.79, 1390, 37.28	0.46 6.191, 116.6, 10.8	N/A
		5	0.22 78.98, 1453, 38.12	0.87 7.263, 133.6, 11.56	N/A
		10	0.13 82.23, 29760, 175.5	N/A	N/A
	MOD2	1	0.13 84.22, 8595, 92.71	N/A	N/A
		5	0.18 87.38, 40350, 200.9	N/A	N/A
		10	0.22 63.75, 18650, 136.6	N/A	N/A

TABLE 6
Spectral Analysis for RI

Table 6. Spectral analysis data for the right-index finger of well-practiced (a) and beginner (b) participants. For each component, top number represents frequency (f) of the peak (cycles/second), and bottom numbers represent variance fraction (%), variance (F), and standard deviation (SD), respectively. For each scale, component that contributes most to the variance is shaded.

			Well-Practiced (f, %, F, SD)		
FINGER	CONDTION	SCALE	**Component 1**	**Component 2**	**Component 3**
RI	CTL	1	0.14 60.99, 5395, 73.45	0.49 8.522, 753.8, 27.46	N/A
		5	0.22 75.23, 11330, 106.5	N/A	N/A
		10	0.23 51.25, 6520, 80.75	0.62 17.01, 2164, 46.52	N/A
	MOD1	1	0.06 44.98, 7353, 87.75	0.28 17.73, 2898, 53.83	N/A
		5	0.11 47.84, 14120, 118.8	0.26 16.68, 4925, 70.18	0.40 6.56, 1936, 44
		10	0.03 15.43, 2929, 54.12	0.15 52.18, 9905, 99.52	N/A
	MOD2	1	0.07 51.94, 103400, 321.5	0.18 6.121, 12180, 110.4	N/A
		5	0.08 38.59, 10230, 101.1	0.23 17.38, 4606, 67.87	N/A
		10	0.02 35.1, 41140, 202.8	0.15 15.47, 18140, 134.7	0.25 10.1, 11830, 108.8

(a)

			Beginner (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
RI	CTL	1	0.20 79.64, 2334, 48.31	N/A	N/A
		5	0.24 52.04, 13870, 117.8	1.06 9.17, 2444, 49.44	N/A
		10	0.28 55.95, 430.8, 20.76	0.83 7.01, 53.95, 7.345	1.11 10.09, 77.67, 8.81
	MOD1	1	0.18 50.48, 1152, 33.94	0.40 7.462, 170.3, 13.05	N/A
		5	0.22 29.35, 529.5, 23.01	0.43 13.12, 236.7, 15.39	0.97 16.81, 303.3, 17.42
		10	0.25 32.52, 14560, 120.7	0.50 20.33, 9101, 95.4	0.75 7.54, 3357, 58.09
	MOD2	1	0.07 67.99, 5283, 72.69	N/A	N/A
		5	0.09 57.84, 5143, 71.72	0.37 10.33, 918.7, 30.31	N/A
		10	0.32 68.52, 9334, 96.61	N/A	N/A

TABLE 7
Spectral Analysis for RM

Table 7. Spectral analysis data for the right-middle finger of well-practiced (a) and beginner (b) participants. For each component, top number represents frequency (f) of the peak (cycles/second), and bottom numbers represent variance fraction (%), variance (F), and standard deviation (SD), respectively. For each scale, component that contributes most to the variance is shaded.

			Well-Practiced (f, %, F, SD)		
FINGER	CONDTION	SCALE	**Component 1**	**Component 2**	**Component 3**
RM	CTL	1	0.07 16.81, 5179, 71.97	0.21 35.24, 10860, 104.2	0.42 9.75, 3003, 54.8
		5	0.09 23.96, 5440, 73.76	0.35 51.58, 11710, 108.2	0.88 10.75, 2441, 49.4
		10	0.08 10.74, 2600, 50.99	0.23 57.44, 13910, 117.9	N/A
	MOD1	1	0.06 24.24, 2595, 50.94	0.15 32.5, 3479, 58.98	N/A
		5	0.05 20.72, 3838, 61.95	0.18 16.12, 2985, 54.64	0.33 15.97, 2958, 54.39
		10	0.12 8.41, 2307, 48.03	0.34 28.27, 7757, 88.07	N/A
	MOD2	1	0.04 28.67, 2495, 49.95	0.30 20.09, 1749, 41.82	N/A
		5	0.08 39.38, 1969, 44.38	0.31 26.1, 1305, 36.13	N/A
		10	0.06 17.72, 7860, 88.66	0.23 47.59, 21110, 145.3	0.43 8.90, 3947, 62.83

(a)

			Beginner (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
RM	CTL	1	0.10 17.45, 2209, 47	0.51 19.85, 2512, 50.12	1.01 19.23, 2433, 49.33
		5	0.12 26.06, 1565, 39.56	0.35 13.73, 824.6, 28.72	N/A
		10	0.18 43.54, 601.2, 24.52	N/A	N/A
	MOD1	1	0.09 36.38, 2399, 48.98	N/A	N/A
		5	0.18 46.07, 10460, 102.3	0.88 15.27, 3465, 58.87	N/A
		10	0.61 39.61, 952.2, 30.86	N/A	N/A
	MOD2	1	0.07 35.71, 10110, 100.5	0.2 5.24, 1484, 38.52	0.35 6.75, 1909, 43.7
		5	0.09 30.36, 53490, 231.3	N/A	N/A
		10	0.32 53.42, 15330, 123.8	0.97 17.23, 4945, 70.32	N/A

TABLE 8
Spectral Analysis for RR

Table 8. Spectral analysis data for the right-ring finger of well-practiced (a) and beginner (b) participants. For each component, top number represents frequency (f) of the peak (cycles/second), and bottom numbers represent variance fraction (%), variance (F), and standard deviation (SD), respectively. For each scale, component that contributes most to the variance is shaded.

			Well-Practiced (f, %, F, SD)		
FINGER	CONDTION	SCALE	**Component 1**	**Component 2**	**Component 3**
RR	CTL	1	0.07 38.86, 1643, 40.54	0.28 20.66, 873.6, 29.56	N/A
		5	0.18 49.12, 2183, 46.72	0.44 23.21, 1032, 32.12	0.79 9.844, 437.5, 20.92
		10	0.23 39.11, 1942, 44.07	0.55 11.77, 584.6, 24.18	0.70 13.37, 663.9, 25.77
	MOD1	1	0.10 46.42, 19700, 140.4	0.18 15.72, 6672, 81.68	0.28 14.17, 6013, 77.55
		5	0.04 28.84, 3377, 58.11	0.29 6.508, 762.1, 27.61	0.40 19.94, 2336, 48.33
		10	0.12 25.6, 8216, 90.64	0.19 12.58, 4039, 63.55	0.34 13.51, 4335, 65.84
	MOD2	1	0.04 27.19, 35700, 188.9	N/A	N/A
		5	0.08 32.32, 4240, 65.12	0.31 15.65, 2053, 45.31	N/A
		10	0.02 16.51, 1985, 44.55	0.07 10.29, 1237, 35.18	N/A

(a)

			Beginner (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
RR	CTL	1	0.20 12.89, 1790, 42.3	0.51 24.19, 3360, 57.96	N/A
		5	0.47 28.99, 4125, 64.23	0.94 9.68, 1377, 37.11	N/A
		10	0.28 58.2, 13680, 116.9	0.97 24.1, 5664, 75.26	N/A
	MOD1	1	0.09 53.03, 2227, 47.19	0.37 7.286, 305.9, 17.49	0.74 10.95, 459.8, 21.44
		5	0.12 14.24, 230.4, 15.18	0.48 27.53, 445.4, 21.11	0.96 22.57, 365.2, 19.11
		10	0.13 35.24, 697.9, 26.42	0.38 25.05, 496, 22.27	N/A
	MOD2	1	0.13 68.14, 9946, 99.73	N/A	N/A
		5	0.09 33.85, 8898, 94.33	0.28 17.06, 4486, 66.98	N/A
		10	0.11 22.54, 5773, 75.98	0.32 9.93, 2543, 50.43	0.76 8.71, 2232, 47.24

TABLE 9
Spectral Analysis for RP

Table 10. Spectral analysis data for the right-pinky finger of well-practiced (a) and beginner (b) participants. For each component, top number represents frequency (f) of the peak (cycles/second), and bottom numbers represent variance fraction (%), variance (F), and standard deviation (SD), respectively. For each scale, component that contributes most to the variance is shaded.

			Well-Practiced (f, %, F, SD)		
FINGER	CONDTION	SCALE	**Component 1**	**Component 2**	**Component 3**
RP	CTL	1	0.21 30.65, 7667, 87.56	0.35 25.68, 6423, 80.14	N/A
		5	0.26 55.71, 5311, 72.88	0.53 20.61, 1965, 44.33	N/A
		10	0.23 49.18, 4169, 64.57	N/A	N/A
	MOD1	1	0.06 49.96, 74900, 273.7	0.28 16.57, 24840, 157.6	N/A
		5	0.07 49.55, 14150, 119	0.26 14.6, 4171, 64.58	0.33 11.8, 3369, 58.04
		10	0.11 36.94, 6159, 78.48	0.27 17.2, 2868, 53.55	0.34 5.98, 996.9, 31.57
	MOD2	1	0.07 54.52, 28090, 167.6	0.18 22.55, 11620, 107.8	N/A
		5	0.08 27.78, 3625, 60.21	0.19 16.33, 2130, 46.15	N/A
		10	0.12 35.05, 3652, 60.44	N/A	N/A

(a)

			Beginner (f, %, F, SD)		
FINGER	CONDITION	SCALE	**Component 1**	**Component 2**	**Component 3**
RP	CTL	1	0.10 14.23, 3218, 56.73	0.30 23.96, 5418, 73.61	0.61 20.91, 4729, 68.77
		5	0.47 38.37, 4177, 64.63	N/A	N/A
		10	0.14 21.97, 1119, 33.45	0.56 25.56, 1302, 36.08	1.06 22.19, 1130, 33.62
	MOD1	1	0.09 38.4, 5038, 70.98	N/A	N/A
		5	0.11 76.36, 1222, 34.96	N/A	N/A
		10	0.15 81.19, 1528, 39.09	N/A	N/A
	MOD2	1	0.09 56.73, 5750, 75.83	0.27 10.69, 1084, 32.92	N/A
		5	0.18 54.3, 395.4, 19.88	N/A	N/A
		10	0.17 78.75, 762.1, 27.61	N/A	N/A

APPENDIX B

FIGURES

FIGURE 1
Flute holding positions

Figure 1. Shows the positions of the left and right hands on the traditional flute. The modified flute involves flipping the right hand 180 degrees. Image retrieved from Getty Images.

FIGURE 2
Traditional Flute

Figure 2. Shows the unmodified flute used for the CTL condition.

FIGURE 3
Modified Flute

Figure 3. Shows the modified flute used for the MOD1 and MOD2 conditions.

FIGURE 4
Pressure Sensor Gloves

(a) (b)

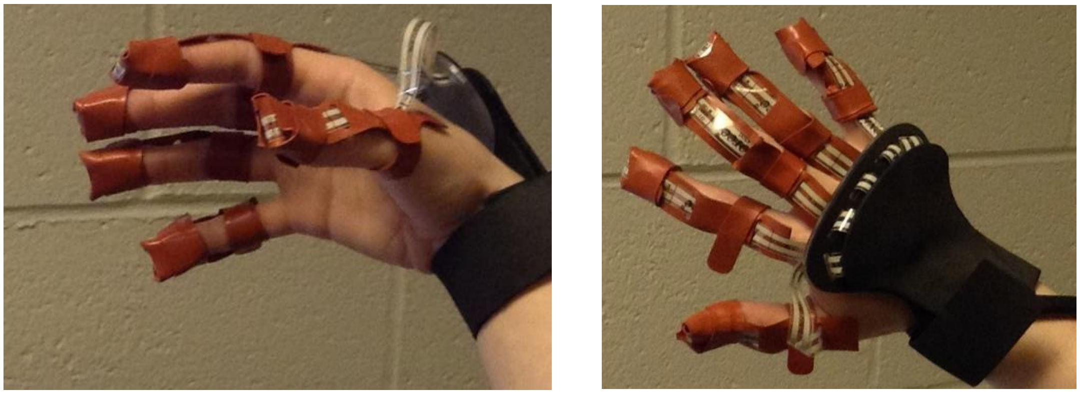

Figure 4. The pressure-sensor gloves used in the experiment: a) palm view, and b) back view.

FIGURE 5
Close-up of Flute Differences


(a)


(b)

Figure 5. The right-hand keys for the unmodified flute (a) and the modified flute (b). Each image is facing the same direction, so that the pinky of the right hand rests on either the key furthest right (a) or the key furthest left (b) in the image.

FIGURE 6
Fingering Charts

(a) (b)

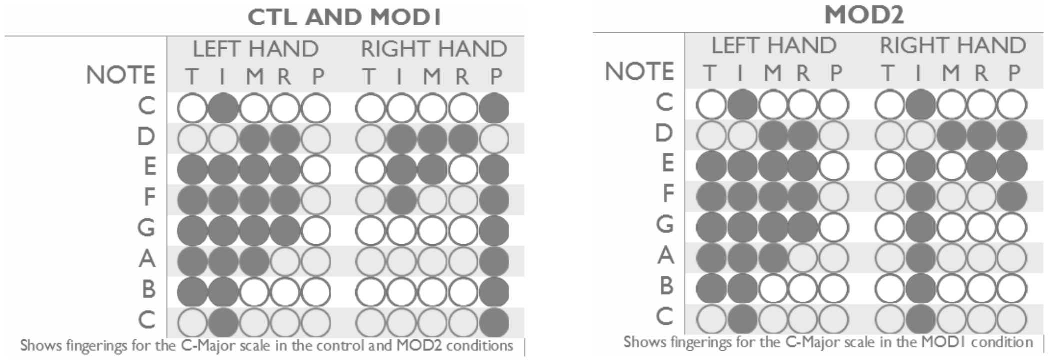

Figure 6. Fingering charts for the three conditions: a) the control and MOD1 conditions, and b) the MOD2 condition. Grey dots represent pressed keys for each note of the C-Major scale. T, I, M, R, and P stand for thumb, index, middle, ring, and pinky fingers respectively.

FIGURE 7
Scale Playing Times

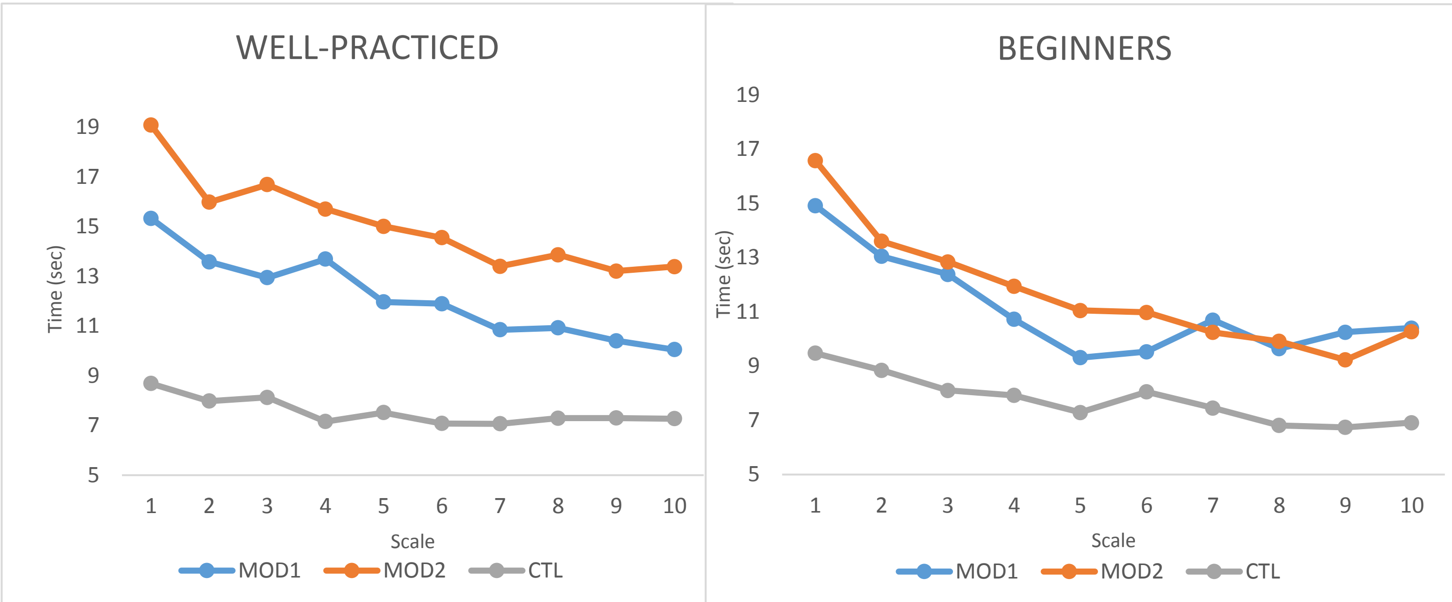

Figure 7a. Shows the averaged scale playing times for each group across the three conditions over ten scales.

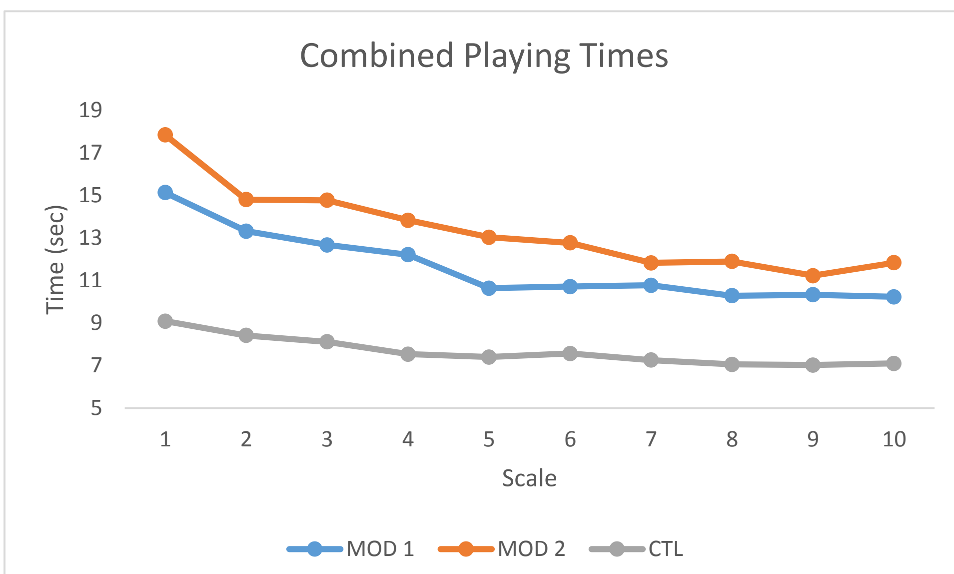

Figure 7b. Shows the average playing time for each scale in MOD1, MOD2, and CTL conditions for both beginning and well-practiced players.

FIGURE 8
Spectral Analysis Legend

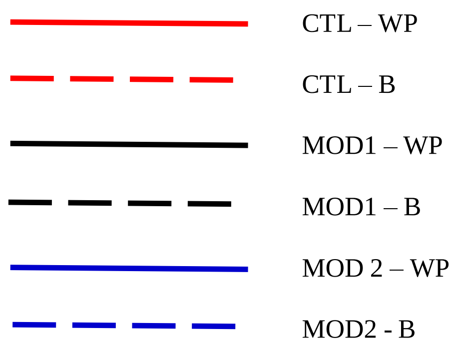

Figure 8. Legend used for all spectral analysis figures.

FIGURE 9
Spectral Analysis Plots for LI

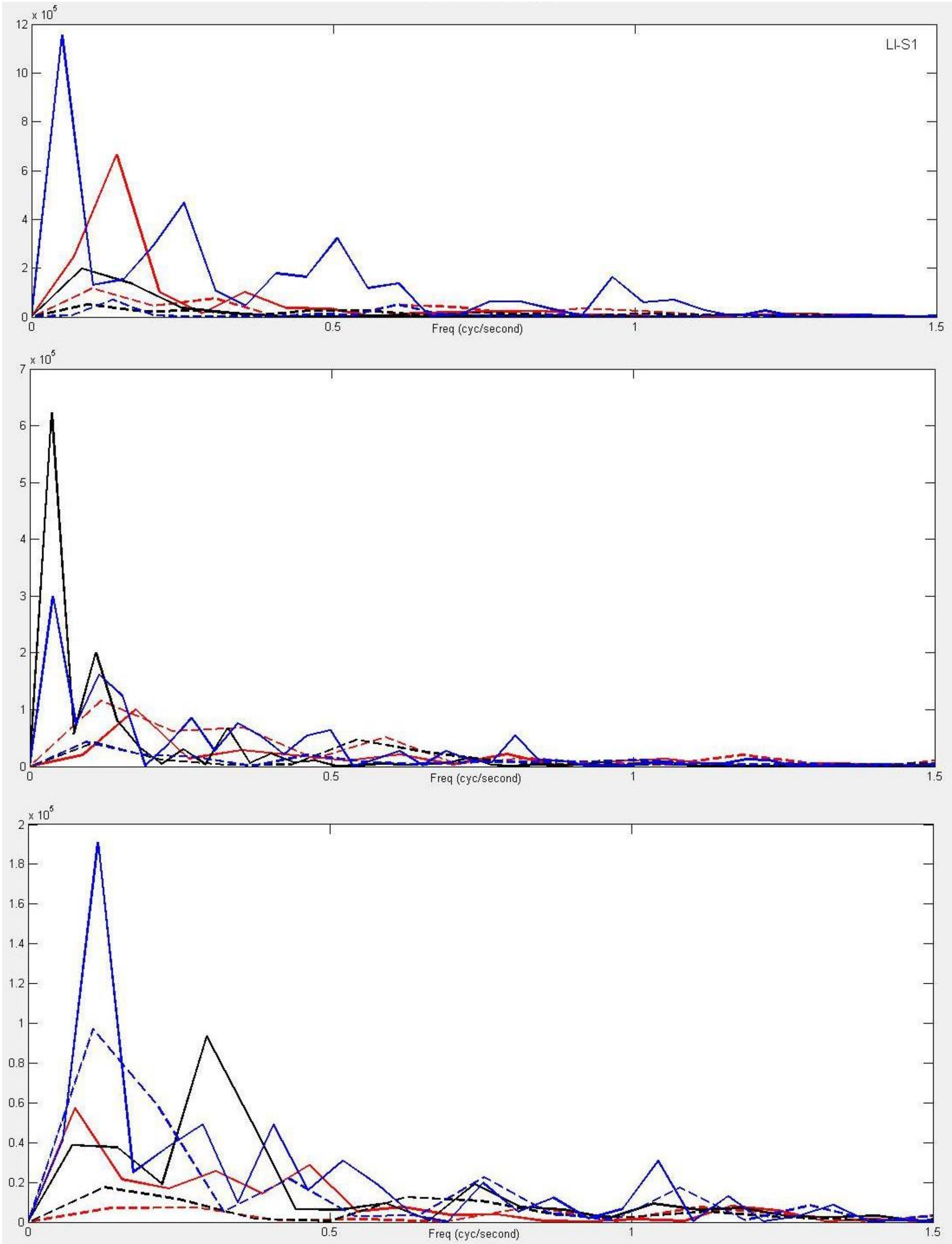

Figure 9. Spectral Analysis plots for left index finger for scale 1 (top), scale 5 (middle), and scale 10 (bottom).

FIGURE 10
Spectral Analysis Plots for LT

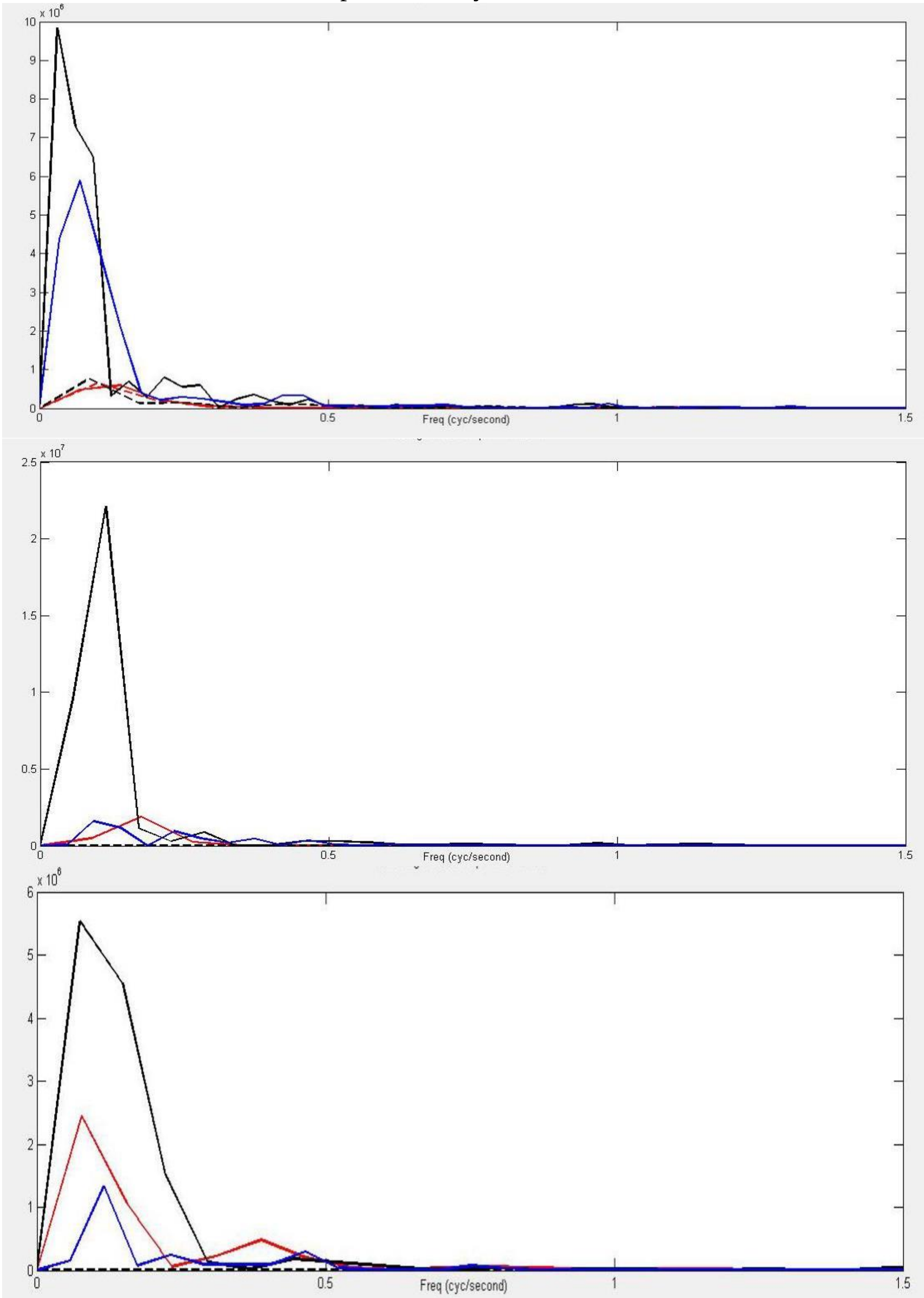

Figure 10. Spectral Analysis plots for left thumb for scale 1 (top), scale 5 (middle), and scale 10 (bottom).

FIGURE 11
Spectral Analysis Plots for LM

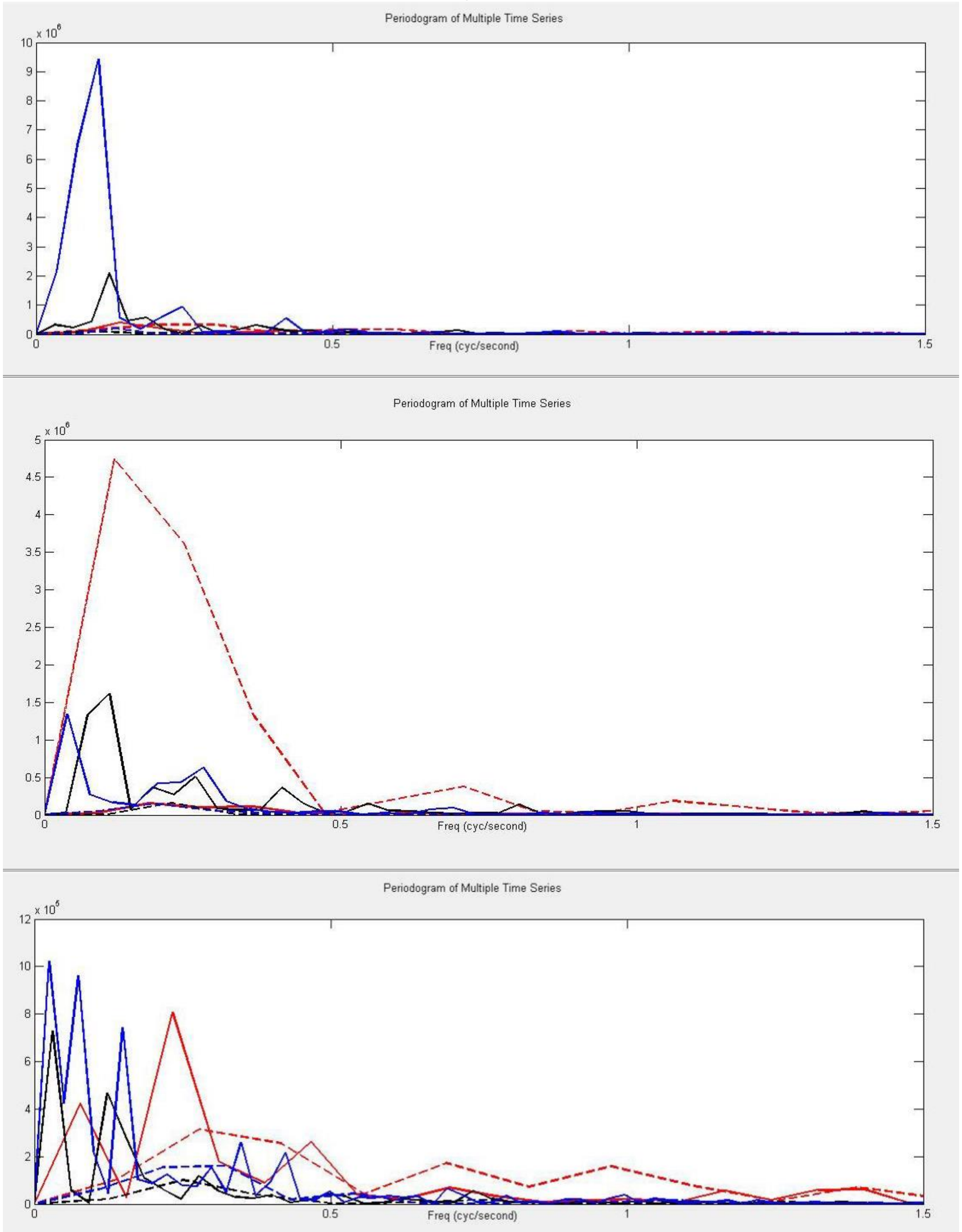

Figure 11. Spectral Analysis plots for left-middle finger for scale 1 (top), scale 5 (middle), and scale 10 (bottom).

FIGURE 12
Spectral Analysis Plots for LR

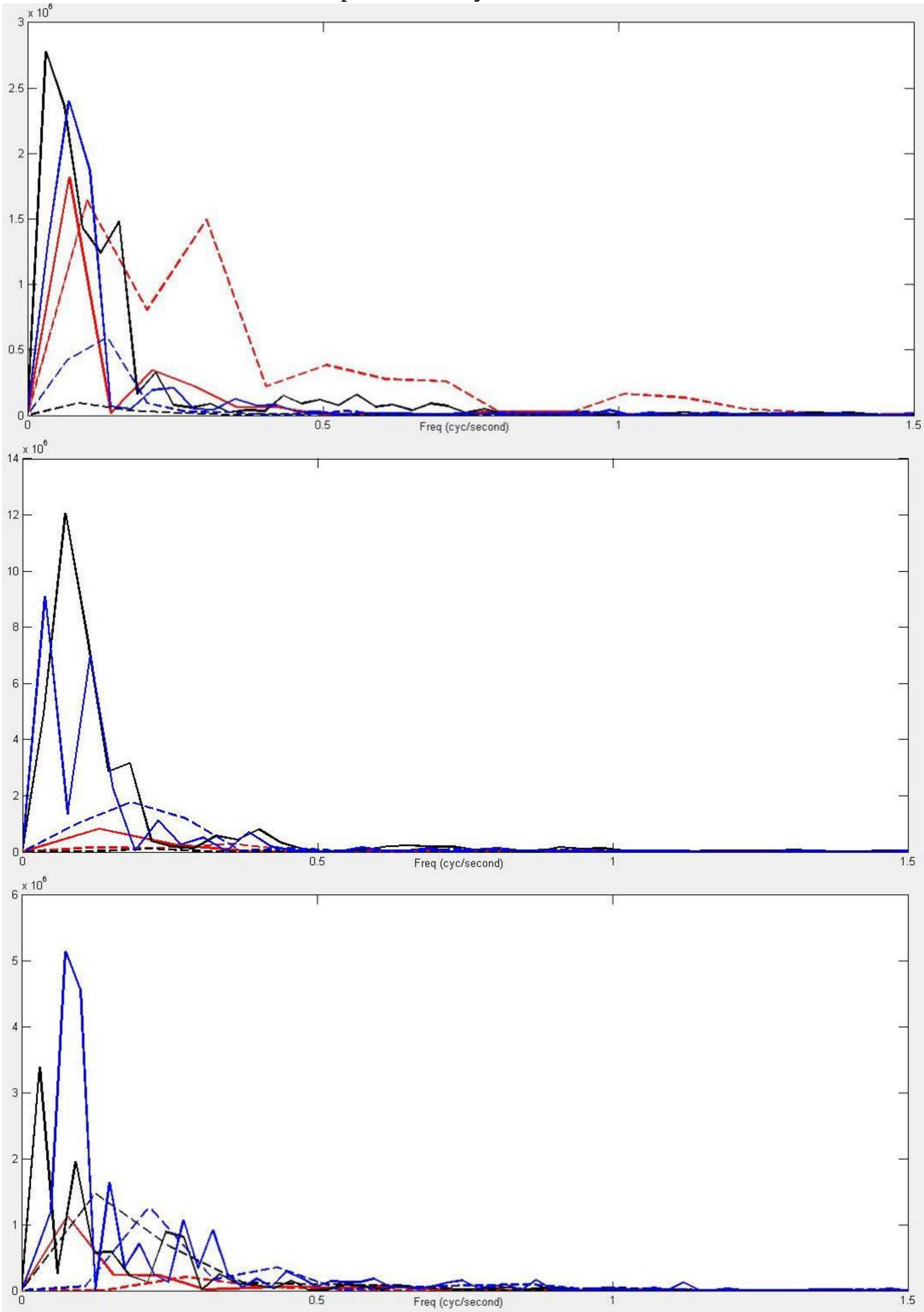

Figure 12. Spectral Analysis plots for left-ring finger for scale 1 (top), scale 5 (middle), and scale 10 (bottom).

FIGURE 13
Spectral Analysis Plots for RI

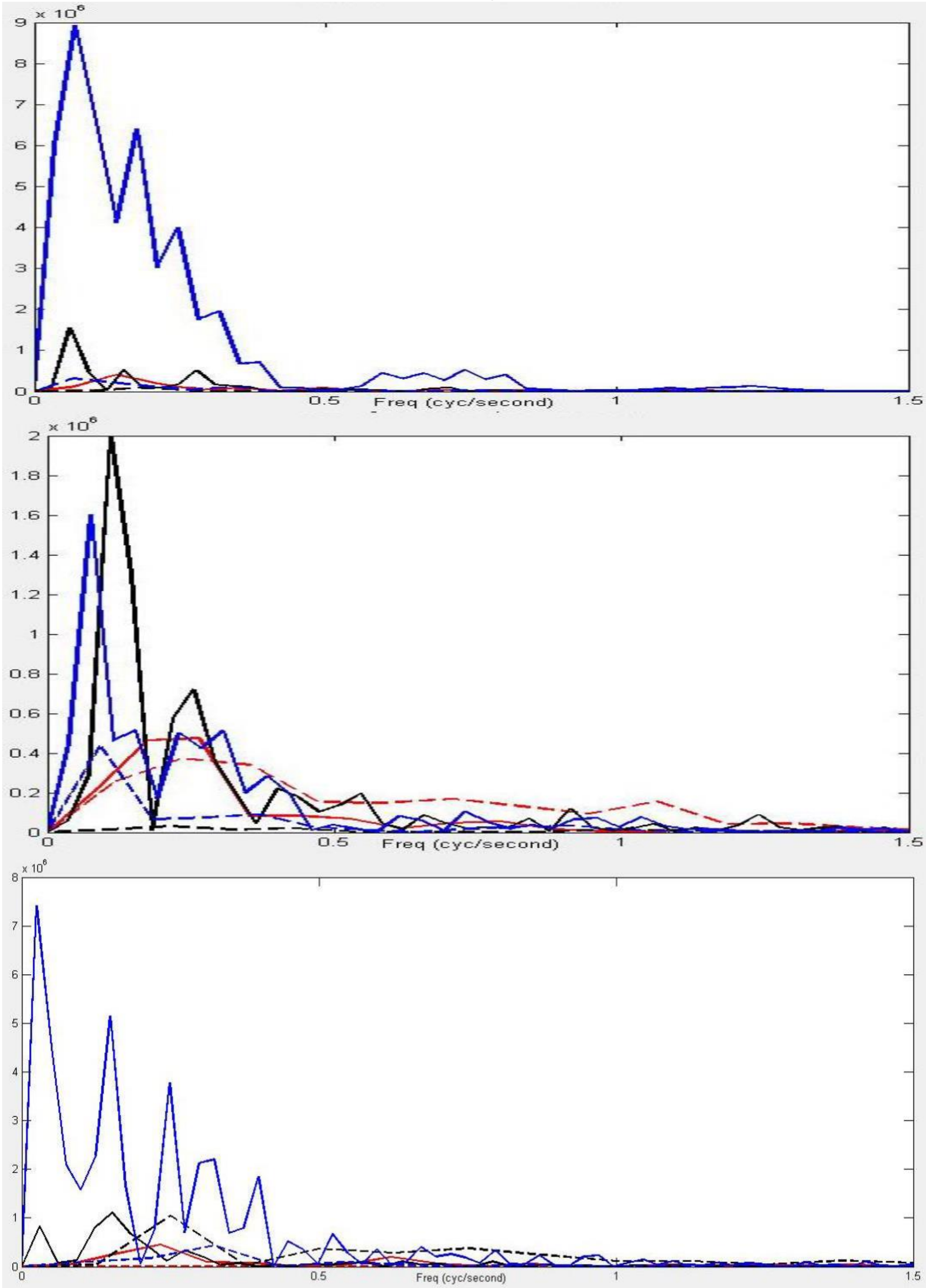

Figure 13. Spectral Analysis plots for right-index finger for scale 1 (top), scale 5 (middle), and scale 10 (bottom).

FIGURE 14
Spectral Analysis Plots for RM

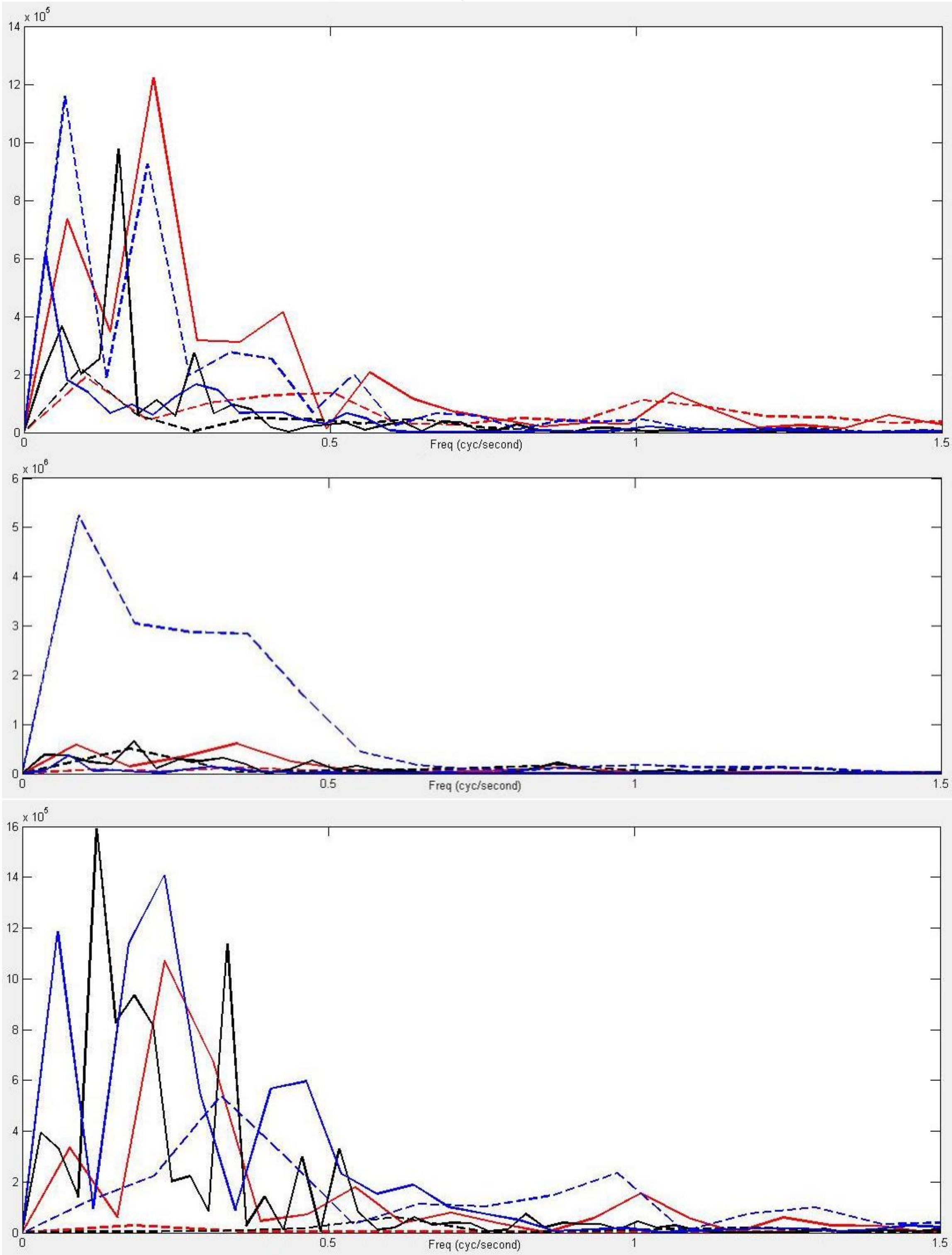

Figure 14. Spectral Analysis plots for right-middle finger for scale 1 (top), scale 5 (middle), and scale 10 (bottom).

FIGURE 15
Spectral Analysis Plots for RR

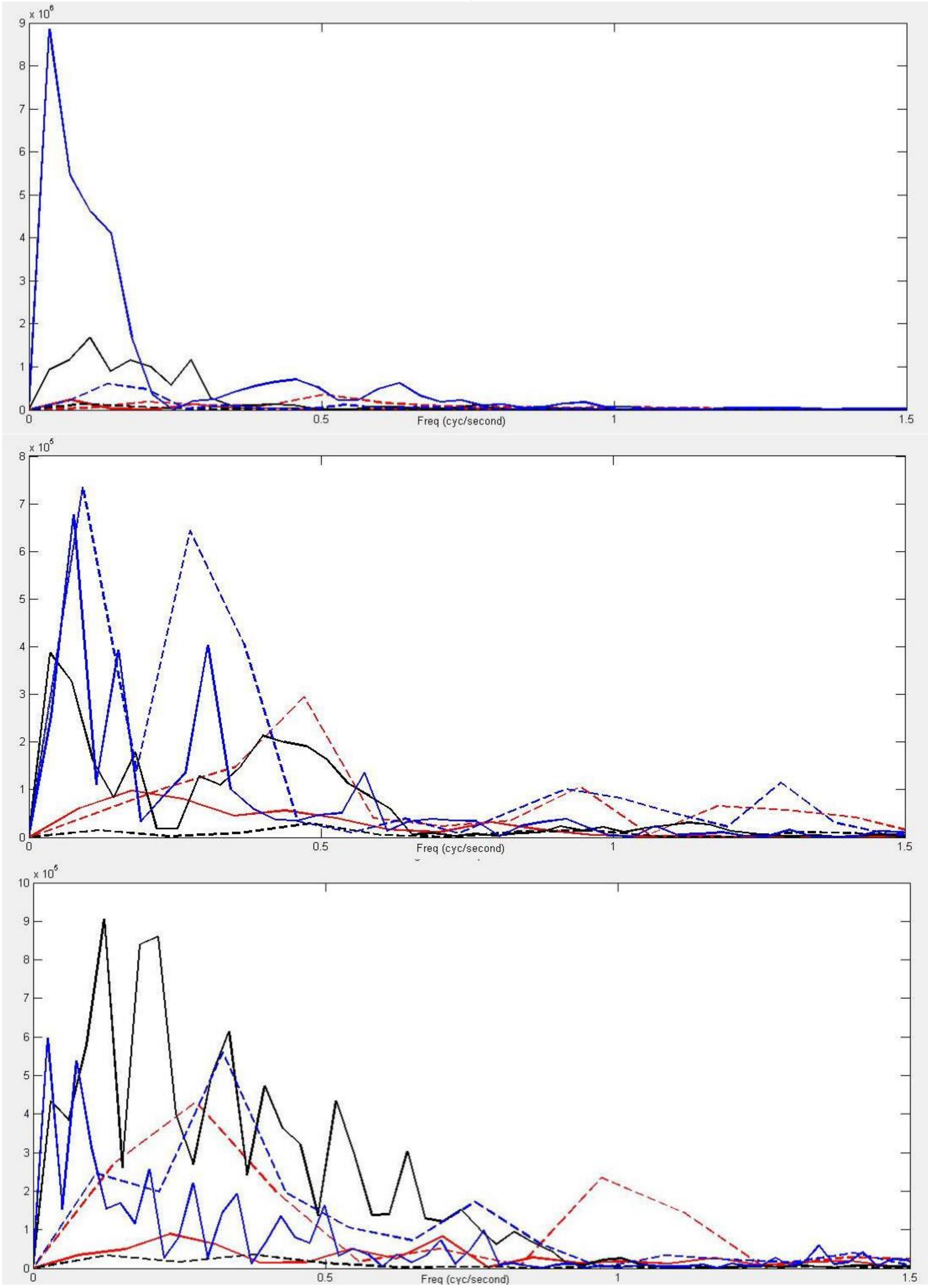

Figure 15. Spectral Analysis plots for right-ring finger for scale 1 (top), scale 5 (middle), and scale 10 (bottom).

FIGURE 16
Spectral Analysis Plots for RP

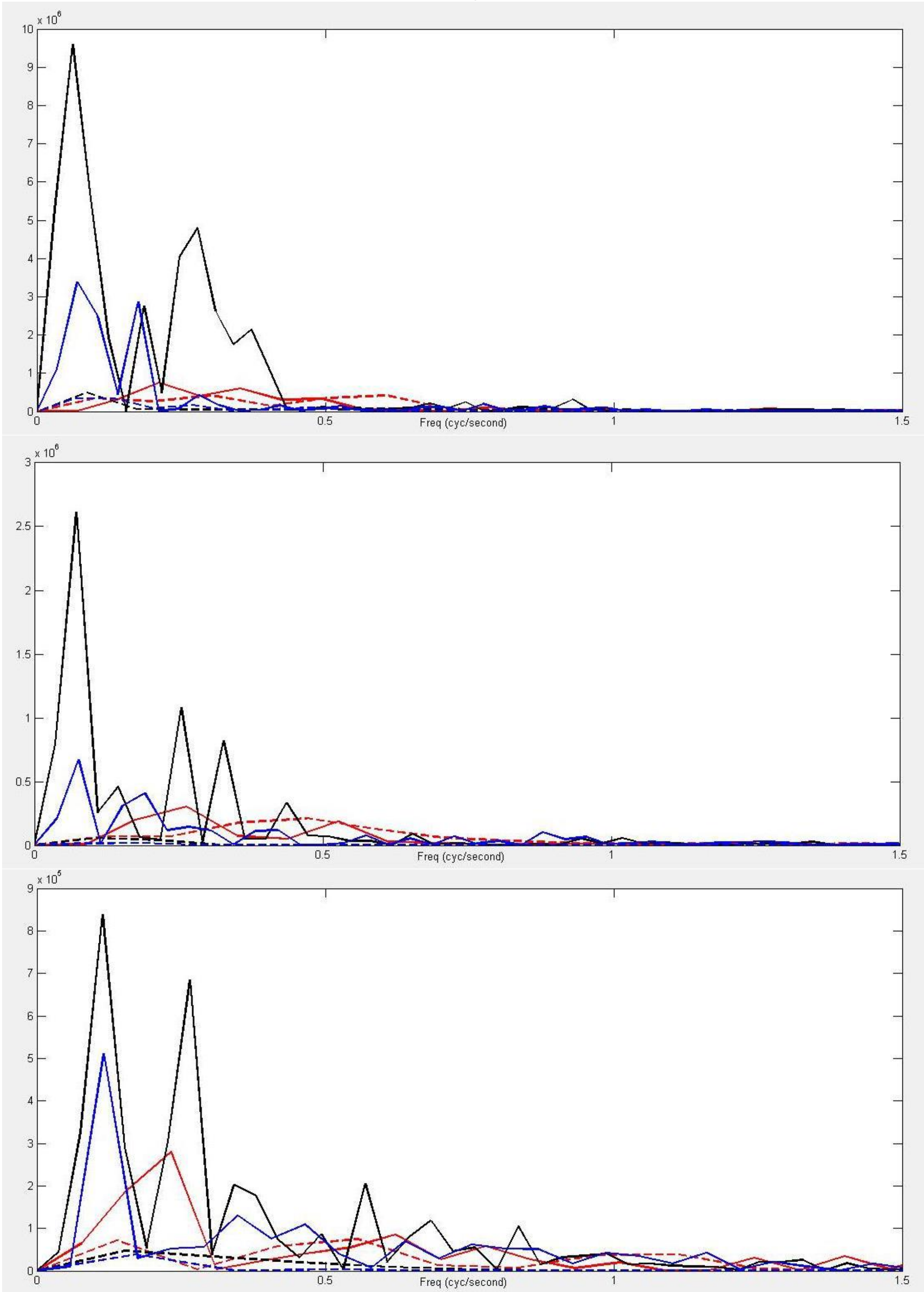

Figure 16. Spectral Analysis plots for right-pinky finger for scale 1 (top), scale 5 (middle), and scale 10 (bottom).

APPENDIX C

QUESTIONNAIRE

The questionnaire (subject information sheet) used for this study is on the following page. No significant differences were found within or between groups in terms of the variables listed (handedness, age, hours of practice, difficulty ratings, etc.).

Subject Number: _______ Date/Time: _________

Condition Order: [ ] Modified/Hands[ ] Modified/Keys[ ] Traditional

Sex: M F Handedness: R L A Age: _________

Years Flute Experience: ____ Years Music Experience: ____ Age of first lesson: ____

Other Instruments Played:

Type of Flute Typically Played:

Open Hole	**Closed Hole**
In-line G	**Off-set G**
C-Foot	**B-Foot**

Hours of Practice (weekly average): ______

Over time, playing the modified flute was easier (than the first time):

No-------------Somewhat-----------Comparable to normal

0	**1**	**2**	**3**	**4**	**5**	**6**	**MODKEY**
0	**1**	**2**	**3**	**4**	**5**	**6**	**MODFIN**

Easiest part: **Most difficult part:**

Additional comments: