EFFECTS OF
BENCH HEIGHT VARIATION
ON MUSCLE ACTIVATION
IN PIANISTS

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by
Sarah Welch
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This thesis has been approved by

The Honors Tutorial College and the School of Music

___________________________________
Dr. Jeff Russell
Assistant Professor of Athletic Training
Thesis Advisor

___________________________________
André Gribou
Professor of Piano, Composition, and General Studies

___________________________________
Jeremy Webster
Dean, Honors Tutorial College
ABSTRACT

Pianists, particularly collegiate and professional pianists, often suffer from debilitating playing-related injuries. Poor playing technique, including inefficient ergonomics, has frequently been forwarded as a cause of these injuries, though the literature lacks epidemiological studies to confirm this causative agent. Arts medicine literature and most piano pedagogy methods suggest that a bench height that produces a forearm horizontal to the floor is the preferable bench height. Therefore, the purpose of this study was to examine the effect of bench height variation, and its resulting effect on forearm position, on pianists’ muscle activation during three specific playing activities. This was undertaken with the clinical goal of determining whether bench height variations, which affect the relative position of the forearm to the floor, impact the playing mechanism. The specific research questions were [1] Which position of the forearm minimizes muscle activation while playing? And [2] Do pianists identify that position as their optimal playing position? The study utilized surface electromyography (sEMG), inertial measurement units (IMUs), and video capture to quantitatively determine the effects of bench height variations, and included a research questionnaire to determine pianists’ experience of different bench heights. The results suggest that no single bench height, physically expressed as forearm orientation, minimizes muscle activation across pianists, and that pianists’ perception of bench height is not always accurate. Implications of these results are discussed, and suggestions for further research are presented.
ACKNOWLEDGEMENTS

This thesis has benefitted from the selfless contributions of several brilliant and talented minds, scientists and artists alike. I count myself privileged to have had the opportunity to learn from these extraordinary people.

I’m grateful to Dr. Christopher Fisher, whose confidence in me turned my small idea into the seed of a full-scale research project, and whose academic and musical guidance has been essential to my development as a scholar, musician, and person throughout and even before my undergraduate years.

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Dr. Jeff Russell has been an extraordinary thesis advisor. His willingness to take on a complex project proposed by an untrained researcher is remarkable, and his guidance and training throughout the process have been thorough and consistent. His confidence in and patience with me are more than I could have asked for. The project has emerged with strong evidence of his guiding hand.

Thanks are also due to Danielle McElhiney from the Athletic Training faculty, who was instrumental in identifying analysis techniques to make sense of the data.

Finally, I’m grateful for the pianists who cheerfully supported this study with their time, and for my family and friends who let me bounce ideas off them, encouraged
me when I was sure it would never be finished, and continuously helped me find creative solutions to a myriad of unexpected problems. It takes a village to write a thesis!

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</tbody>
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Performing artists such as musicians, dancers, and actors often suffer from injuries arising from their artistic activities that prevent them from carrying out these activities. Pianists are among the most frequently injured musicians; studies demonstrate that up to 93% of pianists suffer or have suffered from playing-related musculoskeletal disorders (PRMDs).\(^1\) While this number is high, and while there is vast variation in even the best-conducted studies of PRMD prevalence,\(^1\) given pianists’ intense practice habits and high occupational stress levels,\(^2\) a large number of pianists undoubtedly suffer from PRMDs.

Such playing-related injuries are a focus of the relatively new field of performing arts medicine (PAM). This field is distinct from music and art therapy in which music or art is used as a treatment for medical conditions. Instead, PAM practitioners seek to treat disorders arising from or related to arts practice. These practitioners may be medical doctors in general practice or in specializations such as neurology, physical or occupational therapists, athletic trainers, or members of a number of other fields. Performing arts medicine is a challenging, interdisciplinary field of practice, since artists often lack medical knowledge, and medical practitioners often lack knowledge of the nuances of performing arts;\(^3\) this can cause a substantial disconnect between artists and medical practitioners.

A wide variety of factors put musicians at increased risk for overuse injuries. Although there is not significant agreement in performing arts medicine literature on
what those risk factors are, suggested risk factors include small hand size,\textsuperscript{10} playing habits,\textsuperscript{4} repertoire,\textsuperscript{4,5} gender,\textsuperscript{2,6} and playing posture/ergonomics/technique.\textsuperscript{6-10}

A small segment of performing arts medicine literature has examined the effects of particular variations in pianists’ technique. However, this literature has focused on technique modifications in the wrist, and has represented the disconnect between arts medicine researchers and musicians by examining motions with minimal correspondence to pianists’ actual playing habits. No study could be located that has examined bench height as a variable, and many studies have neglected even to control for bench height or forearm angle as variables.\textsuperscript{7,8} Those studies that did control forearm position as a variable measured it as an angle from the upper arm, not the angle of the forearm from horizontal.\textsuperscript{6,10} An examination of piano technique and pedagogy books for children\textsuperscript{11-15} and adults\textsuperscript{16-18} indicates that pianists discuss forearm position as an angle of the forearm with respect to the horizontal, not the upper arm. The results of this study will be more meaningful for pianists if pianistic motions are examined in a manner pianists will be able to apply to their previous technical training. Therefore, while this study examines the effects of bench height changes on muscle activation in pianists, these changes are expressed physically as variations in the angle of the forearm from the horizontal plane.

Several studies have demonstrated the value of surface electromyography (sEMG) for assessing muscle activation patterns in pianists. One examined the effect of different wrist-related techniques on forearm muscle activation.\textsuperscript{19} Others applied sEMG biofeedback systems to rehabilitation of various PRMDs in pianists.\textsuperscript{20-22} These studies suggest the potential for more thorough examination of muscle activation patterns in pianists in connection with different variables such as forearm angle.
Background

Many aspects of piano technique are hotly disputed among different technical schools of thought. For example, one contemporary school of technique prescribes a smooth, lateral motion of the wrist to create a seamless transfer of sound between notes, with minimal movement of the fingers,\textsuperscript{23} while another approach advocates keeping the wrist steady and executing the transfer by lifting each individual finger in turn.\textsuperscript{24} Piano technique has also evolved through time, with earlier piano technique primarily focused on playing with maximal finger independence and clarity, achieved by lifting the fingers very high and holding the wrists absolutely still.\textsuperscript{25} For the most part, modern piano teachers now reject this playing style, but no absolute “gold standard” of piano technique exists.

One principle of piano technique is nearly universal. The authors of most major introductory piano methods advocate adjusting the piano bench to achieve an approximately horizontal forearm.\textsuperscript{11-18} Those which do not advocate adjusting the bench to achieve this goal simply neglect the issue of posture at the piano entirely,\textsuperscript{26, 27} perhaps assuming that this posture is so well established as to not necessitate mention. Of course, in a field so subjective and individual as piano technique, notable exceptions to this principle do exist.

Perhaps the best-known pianist who rejected this rule was Glenn Gould, a Canadian pianist most famous for his Bach recordings. Gould travelled to concerts with the same chair for his entire concert career, and famously sat very low.\textsuperscript{28} In fact, Gould’s infamous choice of an exaggerated angle of the forearm from the horizontal actually
helps prove the universal acceptance of the horizontal forearm as the standard for good technique: that it was considered exceptional indicates that there is an accepted standard for normal.

While piano teachers generally prescribe this horizontal forearm standard, and while performing arts medicine practitioners consider ergonomics to be an important factor in preventing overuse injuries, no research currently exists to indicate that the horizontal forearm is actually the biomechanically ideal posture for playing the piano. This project seeks to fill that research gap by answering several highly related research questions and developing methodology that can be applied to similar research questions.

I became aware of this research gap through my experiences as a piano student, a piano teacher, and an injured pianist. After experiencing a series of PRMDs at the outset of my collegiate studies, I developed interests in pedagogy and performing arts medicine, and discovered the need for high-quality research and appropriate research methods in both fields. This project contributes to the body of research in both piano pedagogy and performing arts medicine, and improves the evidenced-based practices of both fields.

The primary tool used to assess the effects of forearm orientation changes on muscle activation was surface electromyography (sEMG). For a muscle contraction to occur, the brain must send electrical currents called action potentials through the muscle. sEMG measures muscle activation by monitoring these action potentials via electrodes attached to the skin. As a non-invasive, non-restrictive tool, sEMG is appropriate for studying muscle activation in pianists during playing activities.

Eight muscle groups were selected as important descriptors of muscle activity during played based on several studies’ methodologies. Each muscle group’s
activity while playing was compared to the muscle’s activity during a maximum effort contraction. This process is known as normalization to Maximum Voluntary Contraction (MVC) and is conducted to facilitate comparison between subjects. The practice is supported by additional studies.\textsuperscript{6,19}

Therefore, in light of this background, the purposes of this research were to identify the effects of bench height variation, physically expressed as forearm orientation, on pianists’ muscle activation and experience of playing.

**Research Questions**

This project answers two related research questions. First, which position of the forearm minimizes muscle activation while playing? Second, do pianists identify that forearm position as their optimal position?

In light of the research on PRMD risk factors in pianists, the aims of this research were to determine whether an ideal forearm orientation with respect to the horizontal exists, what that orientation is, and how non-ideal forearm orientations affect muscle activation in pianists’ upper extremities and upper back during short periods of playing. The study also sought to assess how accurately pianists are able to notice the changes that bench height variation produces in their playing.

**Hypotheses**

The hypotheses for each of the research questions for this thesis are:

1. The bench height that results in a horizontal position of the pianist’s forearm is the optimal position to minimize muscle activation while playing. The null hypothesis is that there is no optimal bench height that minimizes muscle activation during playing.
2. Pianists identify the horizontal position of the forearm as their preferred position during playing. The null hypothesis is that there is no difference among forearm positions that pianists identify as their preferred position.
CHAPTER 2: METHODS

Participants
Participants for this research study were recruited from the pool of students receiving piano instruction at Ohio University, both through the applied piano faculty and the faculty of the Athens Community Music School. Subjects represented a variety of music majors, including undergraduate and graduate performance, music education, music therapy, pedagogy, and composition majors. The study also included one pianist who was not a music major, and one pre-college pianist.

No compensation was offered for participation in the study. Prior to their participation, all participants provided informed consent in accordance with protocols approved by the Ohio University Institutional Review Board (IRB), included in Appendix A.

Twenty pianists were enrolled in the study (6 males, 14 females, mean age = 21.8 ± 3.3 yrs). They represented a broad range of ages, playing expertise levels, average weekly playing time, and injury histories. These data are presented in Table 1 below.

Table 1: Subject Demographics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.8</td>
<td>3.3</td>
<td>17</td>
<td>28</td>
</tr>
<tr>
<td>Playing (years)</td>
<td>14.1</td>
<td>4.1</td>
<td>4</td>
<td>22</td>
</tr>
<tr>
<td>Instruction (years)</td>
<td>13.0</td>
<td>4.4</td>
<td>2</td>
<td>20</td>
</tr>
</tbody>
</table>

Given their variety of majors, subjects unsurprisingly reported a wide variation in weekly playing time. This measurement included time spent practicing as well as time
spent playing during rehearsals, lessons, and classes. On average, they practiced for 21.6 ± 18.26 hours per week, with maximum and minimum of 62 and 2.5 hours. They also reported the day on which their playing time was highest. This daily maximum averaged 4.1 ± 3.08 hours, but ranged from 1 to 11 hours. This data is summarized in Figure 1.

**Figure 1: Subjects' Playing Habits**

![Chart showing playing habits](image)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Playing Habits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Weekly Playing Time</td>
</tr>
<tr>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
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<td>4</td>
<td>30</td>
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<td>5</td>
<td>20</td>
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<tr>
<td>6</td>
<td>10</td>
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<tr>
<td>7</td>
<td>0</td>
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<tr>
<td>8</td>
<td>0</td>
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<tr>
<td>9</td>
<td>0</td>
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<td>10</td>
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<td>11</td>
<td>0</td>
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<td>12</td>
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<td>18</td>
<td>0</td>
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<tr>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

**Terms**

This study examined bench height variations, expressed physically as variations in forearm orientation with respect to horizontal. Subjects played three brief excerpts, described in further detail below, at each of four different forearm orientations. Forearm orientations examined were the subject’s preferred orientation, +10° (above horizontal), –10° (below horizontal), and 0° (horizontal). Adjusting the bench height lower produces positive angles of the forearm from horizontal, and adjusting the bench height higher produces negative angles of the forearm from horizontal. Figure 2 illustrates this.
relationship and the nomenclature we have adopted to describe the relationship between bench height and forearm orientation.

Figure 2A-C: The Relationship of Bench Height and Forearm Orientation.
(A) 0° (horizontal forearm)  
(B) +10° (“low” bench)  
(C) –10° (“high” bench)

**Procedures**  
The muscle activation pattern prompted by each angle of the forearm from the horizontal can be measured quantitatively using surface electromyography (sEMG). The Direct Transmission System (DTS), a wireless sEMG system manufactured by Noraxon USA (Scottsdale, Arizona), was used to monitor four muscle groups on each side of the body (eight muscle groups total). Muscle groups monitored bilaterally were the biceps brachii, triceps brachii, upper trapezius, and extensor carpi radialis brevis. The sEMG data for each muscle group was normalized to the Maximum Voluntary Contraction (MVC) for each muscle group, which was measured at the beginning of the procedure. This allowed for inter-subject comparison of sEMG data as percent MVC.
We measured the subjects’ forearm orientations at different bench heights using an Inertial Measurement Unit (IMU), also manufactured by Noraxon. This device works in synchronization with the sEMG system. The IMU is a small body-worn sensor that uses a combination of accelerometers, gyroscopes, and magnetometers to provide data on the pitch, slope, and course of a particular body segment, providing a real-time 3D model of its motion. To our knowledge, this type of body-worn sensor has not previously been used in combination with sEMG to evaluate pianists’ motions.

We also acquired demographic and background data on each subject through a research questionnaire (Appendix C) and utilized video recording to provide supplemental information as described in subsequent sections.

Each pianist played three excerpts at each bench height, and bench height order was randomly assigned. The excerpts were chosen to demonstrate a variety of motions which are typical to piano playing; as mentioned previously, failure to include realistic playing motions has been a shortcoming of previous research in this area.

The first excerpt each subject played was a simple technical exercise known as a five-finger pattern (Appendix D). The five-finger pattern is a standard part of pianists’ training, and was selected as an ideal vehicle for examining analogous motions across pianists.

Second, each subject performed a sight-reading activity. The piece performed was again the same across all subjects: Waltz in C Major by Anton Diabelli. Based on its inclusion in the popular Masterworks Classics anthologies compiled and edited by Jane Magrath and published by Alfred Publishing, this piece is a standard of pedagogical repertoire. It was selected for its classical pianistic characteristics: broken-chord left hand
accompaniment with cantabile right hand melody, both in typical ranges of the piano. It is at an accessible sight-reading level for the broad range of pianists included in the study. Sight-reading activities represent a significant portion of pianists’ playing activities. We included a sight-reading piece to investigate whether pianists’ muscle activation profiles varied during sight-reading versus playing familiar technical exercises and current repertoire.

Third, each subject performed a brief (approximately 20-second) excerpt from his or her current repertoire. This excerpt was the same for each of the four bench heights within each subject’s data collection, but different across each subject. Allowing each subject to choose his or her current repertoire ensured that he or she was comfortable with the repertoire, and that a variety of pianistic motions were being assessed.

We implemented the following step-by-step procedure to produce consistent results across each subject.

1. Informed Consent Process

Upon a subject’s arrival at the test session, the study was explained. Opportunity was given for the subject to ask questions and have them answered. Appropriate informed consent was obtained (see Appendix B).

2. Instrumentation

The subject completed the demographic and history portions of the questionnaire. The skin was prepared by abrading and isopropyl alcohol; if excess hair was present, it was shaved. Noraxon dual silver/silver chloride sEMG electrodes and their wireless transmitters (Noraxon, Scottsdale, AZ) were affixed to the body with double-sided adhesive over each of the eight muscles being recorded according to the placement guide
contained in the Noraxon MR3 software. A single Noraxon inertial measurement unit was strapped to the subject’s right arm with a Velcro and neoprene strap. The IMU was calibrated with the subject’s forearms resting on a horizontal surface. The subject determined his or her preferred forearm orientation, which was recorded as an angle from the horizontal through the Noraxon MR3 software.

3. Maximum Voluntary Contraction Measurement

The subject performed three MVCs for each muscle group. The first was a practice round, and the final MVC was the maximum of two recorded MVCs. The Noraxon MR3 software automatically selected the maximum of the two measurements and normalized all subsequent sEMG measurements to these values. For the extensor carpi radialis brevis MVC, the subject rested his forearm on a horizontal surface palm-down with the forearm and wrist supported in a neutral position. The subject then extended the wrist against the stationary chain apparatus. For the biceps brachii MVC, the subject flexed his forearm to 90° and pulled palm-up against the chain. For the triceps brachii MVC, the subject flexed his forearm to 90° and pulled palm-down against a chain fixed to an overhead support. For the upper trapezius MVC, the participant fully extended his arm at his side and pulled upwards with his shoulder against a chain fixed to the floor. These MVC tests are shown in Figure 3.
4. Bench Height 1

Bench height orders were randomized to prevent order bias; thus, each subject was assigned a unique bench height order. From its previous setting at the subject’s preferred playing height (Procedure Stage 2), the bench was adjusted to produce the first randomized forearm angle: either the subject’s preferred playing height, the neutral forearm (0° from horizontal), −10° (elbow above wrist), or +10° (elbow below wrist). Accurate measurement was ensured by instructing the subject to place his or her hands in playing position on C Major five-finger patterns starting on C3 (left hand) and C5 (right hand). At the first bench height, the subject performed a five-finger pattern (see Appendix D), simple sight-reading selection (see Appendix E), and excerpt from his or her own current repertoire. He described the bench height as his normal height, higher or lower than usual, or unknown, and described the bench height’s effect on his playing as positive, negative, or neutral.
5. Bench Height 2

The bench was adjusted to produce the second desired angle of the forearm using the same procedure as before. At the second bench height, the subject performed the same five-finger pattern, sight-reading selection, and excerpt from his or her repertoire, and answered the same questions on the research questionnaire.

6. Bench Height 3

The bench was adjusted to produce the third desired angle of the forearm using the same procedure as before. At this bench height, the subject performed the same five-finger pattern, sight-reading selection, and excerpt from his or her repertoire, and answered the same questions on the research questionnaire.

7. Bench Height 4

The bench was adjusted to produce the final desired angle of the forearm using the same procedure as before. At this bench height, the subject performed the same five-finger pattern, sight-reading selection, and excerpt from his or her repertoire, and answered the same questions on the research questionnaire. Following the final bench height, the subject’s electrodes were removed and discarded.

Post-Processing

The sEMG data were subjected to two post-processing procedures in the Noraxon MR3 software. First, RMS signal smoothing was applied with time window of 100 ms. This standard procedure allows trends in the sEMG data to be observed more easily. It also rectifies the sEMG signals; this means that signals are converted from having both positive and negative components to having only positive components. This allows for
calculations on the data. Second, post-hoc amplitude normalization was utilized to compare the muscle contractions while playing to the subject’s MVC values.

**Data Analysis**

Subjects’ research questionnaire responses were coded and compared. Means, ranges, and standard deviations were computed for demographic information. Responses to opinion questions were summarized in data tables. Responses to the bench height comparison questions were assessed as true or false and summarized in data tables. Responses to questions on the impact of the bench height on quality of playing were summarized graphically.

Data from sEMG testing were analyzed using the SPSS statistics package (IBM, Armonk, NY). Data were grouped by muscle, side, and playing activity. Within each group, a Wilks’ Lambda multivariate analysis of variance (ANOVA) was performed to determine whether bench height variation caused statistically significant changes in muscle activation. In instances when Mauchly’s Test of Sphericity indicated that sphericity violations invalidated the Wilks’ Lambda analysis, a Huyhn-Feldt correction was used instead. The Huyhn-Feldt correction was chosen over the Greenhouse-Geisser correction based on its superior fit to the data. The bench heights that produced statistically significant differences in muscle activation were identified through this procedure, and were further analyzed with a paired t-test with Bonferroni correction.
CHAPTER 3: RESULTS

Injury Histories

Subjects were asked via the research questionnaire whether they had ever experienced an episode of playing-related pain that caused them to miss one or more lessons, classes, rehearsals, or other playing obligations. Subsequent questions identified more information about these injury experiences. Only two subjects indicated that they had experienced such an episode; however, eight more subjects answered follow-up questions indicating that they had experienced episodes of playing-related pain, but had not cancelled any playing obligations.

The two subjects who had missed playing obligations had experienced 1-2 and 3-4 such episodes of playing-related pain. Both had experienced pain in the fingers and hand, and one had additionally experienced pain in the wrist, for a combined total of five painful sites. Both had experienced at least one of these episodes within the last year.

The eight subjects who had experienced significant playing-related pain, but had not missed playing obligations because of it, reported a combined total of 36 sites of pain (Table 2). These eight subjects averaged 3.2 ± 1.0 sites of pain (range = 1 to 5).

Table 2: Number of Subjects Reporting Pain in Various Anatomical Sites

<table>
<thead>
<tr>
<th></th>
<th>Finger</th>
<th>Hand</th>
<th>Wrist</th>
<th>Forearm</th>
<th>Elbow</th>
<th>Shoulder</th>
<th>Neck</th>
<th>Upper Back</th>
<th>Middle Back</th>
<th>Lower Back</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Opinions on Bench Height

As discussed in the Methods section, we considered forearm orientation as an indirect reporting of bench height. Bench height and forearm orientation exhibit an inverse correlation, with lower bench heights producing larger positive angles of the forearm from horizontal, and vice versa.

Subjects were asked four questions to examine their opinions and practices related to bench height adjustments. Although the subjects agreed on the importance of bench height to injury prevention and sound quality, not all practiced consistently with an adjustable bench. The results are summarized in Table 3.

Table 3: Subjects' Opinions About Bench Height

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Disagree</th>
<th>Somewhat Disagree</th>
<th>Neutral</th>
<th>Somewhat Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think bench height is important to reducing the risk of playing-related pain or injury.</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>I pay careful attention to my bench height before and during practice.</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>The height at which I set my bench impacts the sound I produce.</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I ___ use an adjustable bench in my practice.</th>
<th>Never</th>
<th>Occasionally</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

After being instrumented, subjects were asked to select the bench height that produced the forearm orientation with which they would normally play. The average bench height selected yielded a mean forearm angle of -2.5° ± 6.8°. This indicates a wide variation in preference; indeed the maximum angle below horizontal selected was -19.8° and the maximum angle above horizontal was +13.2°. Except for the two pianists at the
extremes, the subjects’ preferred forearm orientations were all within ±10° of horizontal. With the outliers removed, then, the range was -9.5° below horizontal to +5.5° above horizontal, with mean 2.41° ± 4.3°. The preferred forearm orientations, expressed in degrees from horizontal, with outliers included, are summarized below in Figure 4.

Figure 4: Preferred Forearm Orientations

Joint Position Sense: Accuracy

After performing three playing activities at a given bench height, subjects were asked to evaluate the bench height for its effect on their playing and its height relative to their normal bench height. Their responses were marked as true or false to examine the accuracy of the participants’ perceptions of bench height.

At the bench height that corresponded to a forearm position of –10°, 17 subjects correctly assessed the bench height’s relationship to their normal bench height. However,
at the bench height that corresponded to a 0° position of the forearm, only 6 subjects correctly assessed the bench height. With bench height low and the forearm +10°, 15 subjects correctly assessed the bench height compared to their normal bench height. Only 10 subjects correctly identified their preferred bench height from the randomized order of bench heights.

**Muscle Activation Data**

Figures 5 and 6 are useful visualizations of the sEMG data. On the horizontal axis, 1 corresponds to the “low” bench height, or a forearm angle of +10°; 2 corresponds to the recommended bench height, or a forearm angle of 0°; 3 corresponds to the “high” bench height, or a forearm angle of −10°; and 4 corresponds to a subject’s preferred bench height. Each line represents a particular muscle group’s trends over the four bench heights, with the vertical axis representing muscle contraction levels as percent of MVC. Thus, the lowest point for each line shows the bench height that minimized that particular muscle. Each chart represents one side during one playing activity. To create these charts, the mean muscle activation over the course of the playing activity was determined for each muscle and each subject. All subjects’ mean activations were then averaged to produce a single mean representing the muscle activation for a particular muscle, playing activity, and bench height.
Figure 5: sEMG Data - Left Side

**Left 5-Finger Pattern**

- Extensors
- Biceps
- Triceps
- Trapezius

**Left Sight-Reading**

- Extensors
- Biceps
- Triceps
- Trapezius

**Left Excerpt**

- Extensors
- Biceps
- Triceps
- Trapezius
Figure 6: sEMG Data - Right Side

**Right 5-Finger Pattern**

Muscle Contraction (% MVC) vs. Bench Height

- Extensors
- Biceps
- Triceps
- Trapezius

**Right Sight-Reading**

Muscle Contraction (% MVC) vs. Bench Height

- Extensors
- Biceps
- Triceps
- Trapezius

**Right Excerpt**

Muscle Contraction (% MVC) vs. Bench Height

- Extensors
- Biceps
- Triceps
- Trapezius
Table 4 shows results from the Wilks’ Lambda ANOVA procedure. Table 5 shows results from the Huynh-Feldt univariate data correction, applied to all data sets that exhibited sphericity issues when the Wilks’ Lambda statistic was used.

Table 4: Wilks' Lambda ANOVA. Boldface denotes statistical significance.

<table>
<thead>
<tr>
<th>Trial</th>
<th>F</th>
<th>Degrees of Freedom</th>
<th>Significance</th>
<th>Sphericity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5-Finger Pattern</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Extensors</td>
<td>1.202</td>
<td>3, 17</td>
<td>.339</td>
<td>.032</td>
</tr>
<tr>
<td>Left Biceps</td>
<td>2.165</td>
<td>3, 17</td>
<td>.085</td>
<td>.516</td>
</tr>
<tr>
<td>Left Triceps</td>
<td>1.288</td>
<td>3, 17</td>
<td>.310</td>
<td>.516</td>
</tr>
<tr>
<td>Left Trapezius</td>
<td>.300</td>
<td>3, 17</td>
<td>.825</td>
<td>.016</td>
</tr>
<tr>
<td><strong>Sight-Reading</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Extensors</td>
<td>2.236</td>
<td>3, 17</td>
<td>.121</td>
<td>.061</td>
</tr>
<tr>
<td>Left Biceps</td>
<td>1.045</td>
<td>3, 17</td>
<td>.398</td>
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<tr>
<td>Left Triceps</td>
<td>1.940</td>
<td>3, 17</td>
<td>.161</td>
<td>.214</td>
</tr>
<tr>
<td>Left Trapezius</td>
<td>.802</td>
<td>3, 17</td>
<td>.510</td>
<td>.086</td>
</tr>
<tr>
<td><strong>Excerpt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Extensors</td>
<td>.828</td>
<td>3, 17</td>
<td>.496</td>
<td>.815</td>
</tr>
<tr>
<td><strong>Left Biceps</strong></td>
<td>3.192</td>
<td>3, 17</td>
<td><strong>.050</strong></td>
<td><strong>.101</strong></td>
</tr>
<tr>
<td>Left Triceps</td>
<td>1.666</td>
<td>3, 17</td>
<td>.212</td>
<td>.015</td>
</tr>
<tr>
<td>Left Trapezius</td>
<td>.722</td>
<td>3, 17</td>
<td>.553</td>
<td>.053</td>
</tr>
<tr>
<td><strong>5-Finger Pattern</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Extensors</td>
<td>1.081</td>
<td>3, 17</td>
<td>.384</td>
<td>.190</td>
</tr>
<tr>
<td>Right Biceps</td>
<td>.876</td>
<td>3, 17</td>
<td>.473</td>
<td>.018</td>
</tr>
<tr>
<td>Right Triceps</td>
<td>.452</td>
<td>3, 17</td>
<td>.719</td>
<td>.265</td>
</tr>
<tr>
<td>Right Trapezius</td>
<td>2.093</td>
<td>3, 17</td>
<td>.139</td>
<td>.041</td>
</tr>
<tr>
<td><strong>Sight-Reading</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Extensors</td>
<td>2.575</td>
<td>3, 17</td>
<td>.088</td>
<td>.578</td>
</tr>
<tr>
<td>Right Biceps</td>
<td>.830</td>
<td>3, 17</td>
<td>.496</td>
<td>.591</td>
</tr>
<tr>
<td>Right Triceps</td>
<td>1.518</td>
<td>3, 17</td>
<td>.246</td>
<td>.001</td>
</tr>
<tr>
<td><strong>Right Trapezius</strong></td>
<td>4.037</td>
<td>3, 17</td>
<td><strong>.024</strong></td>
<td><strong>.806</strong></td>
</tr>
<tr>
<td><strong>Excerpt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Right Extensors</strong></td>
<td>3.294</td>
<td>3, 17</td>
<td><strong>.046</strong></td>
<td>.118</td>
</tr>
<tr>
<td>Right Biceps</td>
<td>3.491</td>
<td>3, 17</td>
<td>.039</td>
<td>.028</td>
</tr>
<tr>
<td>Right Triceps</td>
<td>4.535</td>
<td>3, 17</td>
<td>.016</td>
<td>.001</td>
</tr>
<tr>
<td>Right Trapezius</td>
<td>2.577</td>
<td>3, 17</td>
<td>.088</td>
<td>.656</td>
</tr>
</tbody>
</table>
Table 5: Huynh-Feldt Corrected sEMG Significance

<table>
<thead>
<tr>
<th>Trial</th>
<th>F</th>
<th>Degrees of Freedom</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Extensors (5FP)</td>
<td>.810</td>
<td>2.420, 45.973</td>
<td>.472</td>
</tr>
<tr>
<td>Left Trapezius (5FP)</td>
<td>.349</td>
<td>2.359, 44.829</td>
<td>.742</td>
</tr>
<tr>
<td>Left Triceps (Excerpt)</td>
<td>1.476</td>
<td>2.215, 42.090</td>
<td>.240</td>
</tr>
<tr>
<td>Left Trapezius (Excerpt)</td>
<td>.775</td>
<td>2.543, 48.320</td>
<td>.495</td>
</tr>
<tr>
<td>Right Biceps (5FP)</td>
<td>1.409</td>
<td>2.416, 45.898</td>
<td>.255</td>
</tr>
<tr>
<td>Right Trapezius (5FP)</td>
<td>2.342</td>
<td>2.462, 46.773</td>
<td>.096</td>
</tr>
<tr>
<td>Right Triceps (Sight-reading)</td>
<td>.791</td>
<td>1.987, 37.760</td>
<td>.460</td>
</tr>
<tr>
<td>Right Biceps (Excerpt)</td>
<td>2.900</td>
<td>2.262, 42.971</td>
<td>.060</td>
</tr>
<tr>
<td>Right Triceps (Excerpt)</td>
<td>1.021</td>
<td>2.158, 40.997</td>
<td>.374</td>
</tr>
</tbody>
</table>

Table 6 presents t-tests of the forearm orientations and excerpts identified as potentially significant by analysis of variance. Note that, for these tests the Bonferroni correction indicates that the threshold for significance is $p < 0.05/6 = 0.083$, since 6 comparisons are being made with each set of t-tests. As previously, 1 corresponds to the “low” bench height, or a forearm position of $+10^\circ$; 2 corresponds to the recommended bench height, or a forearm position of $0^\circ$; 3 corresponds to the “high” bench height, or a forearm position of $-10^\circ$; and 4 corresponds to each subject’s preferred bench height.

Table 6: Paired t-Tests of Potentially Significant Data Sets

<table>
<thead>
<tr>
<th>Trial</th>
<th>Comparison</th>
<th>Mean Difference (I-J)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Trapezius (Sight-reading)</td>
<td>1, 2</td>
<td>1.796</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>1, 3</td>
<td>3.807</td>
<td>.053</td>
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<td></td>
<td>1, 4</td>
<td>2.606</td>
<td>.248</td>
</tr>
<tr>
<td></td>
<td>2, 3</td>
<td>2.011</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>2, 4</td>
<td>.810</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>3, 4</td>
<td>-1.201</td>
<td>1.000</td>
</tr>
<tr>
<td>Right Extensors (Excerpt)</td>
<td>1, 2</td>
<td>-1.562</td>
<td>.788</td>
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<tr>
<td></td>
<td></td>
<td></td>
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<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>1, 2</td>
<td>-2.163</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>1, 3</td>
<td>5.001</td>
<td>.282</td>
<td></td>
</tr>
<tr>
<td>1, 4</td>
<td>1.256</td>
<td>1.000</td>
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</tr>
<tr>
<td>2, 3</td>
<td>7.163</td>
<td>.054</td>
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<tr>
<td>2, 4</td>
<td>3.419</td>
<td>1.000</td>
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</tr>
<tr>
<td>3, 4</td>
<td>-3.745</td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>

**Left Biceps (Excerpt)**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 3</td>
<td>-2.186</td>
<td>.304</td>
</tr>
<tr>
<td>1, 4</td>
<td>-.125</td>
<td>1.000</td>
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<td>2, 3</td>
<td>-.624</td>
<td>1.000</td>
</tr>
<tr>
<td>2, 4</td>
<td>1.437</td>
<td>1.000</td>
</tr>
<tr>
<td>3, 4</td>
<td>2.061</td>
<td>.914</td>
</tr>
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</table>
CHAPTER 4: DISCUSSION

The aims of this research were to determine whether an ideal forearm orientation with respect to the horizontal exists, what that orientation is, and how non-ideal forearm orientations affect muscle activation in pianists’ upper extremities and upper back during short periods of playing. The study also sought to assess how accurately pianists are able to notice the changes that bench height variation produces in their playing. The study utilized surface electromyography to assess muscle activation during each of three different playing activities at four different bench heights, and a questionnaire to investigate pianists’ experience with those variations.

This experimental design was based on prior studies’ methodologies, but expanded beyond them. In a study by Bejjani et al., variations in a technique were assessed with sEMG monitoring of eight muscle groups in the right upper extremity while the pianist performed three excerpts from Bach’s Well-Tempered Clavier. The present study expanded on that methodology by monitoring several of the same muscle groups bilaterally, incorporating more diverse playing activities, and utilizing more subjects. The selection of diverse playing excerpts is supported by a study by Grieco et al. in which participants played a prepared excerpt which was the same across all subjects, as well as a selection from their own repertoire. That study also supported the procedure of normalizing sEMG data to MVC to allow for comparison between subjects. Another study by Oikawa et al. also utilized the procedure of normalization to MVC to examine claims about technique made by piano pedagogy experts. However, that study did not utilize excerpts from the piano literature.
To assess the results, analysis of variance with accompanying assessments of and corrections for sphericity were utilized to look for statistically significant differences between bench heights for each muscle group monitored; paired t-tests were used to further investigate bench heights of interest identified by this procedure. Data from questionnaires on perception of bench height were characterized as accurate or inaccurate.

These processes yielded some unexpected results. The lack of statistically significant differences in muscle activation between forearm orientations was surprising, since a horizontal forearm has been agreed upon in the literature of piano pedagogy as the ergonomically ideal position for playing the piano, posture and ergonomics have been identified by the arts medicine literature as risk factors for injury, and subjects had strong opinions on their preferred bench heights. It would be expected that either the forearm position accepted as “ideal” or a pianist’s preferred forearm inclination, or both, would result in lower muscle activation because these positions would be the most relaxed for a pianist. This lack of an overall trend in the data may be due to the study’s limitations, or may indicate that (1) bench height does not affect muscle activation, or (2) no single bench height is ideal for all pianists. There may be a single bench height that is most efficient for each subject based on individual physical characteristics; this can be better understood through further analysis of the data obtained through this study, and through further similar studies.

Previous studies have established that individuals who repeatedly engage in tasks requiring joint position sense are more accurate in their ability to replicate joint positions, thus suggesting a proprioceptive training effect. In light of these studies and the high
degree of training of the subjects in this study, the subjects’ pervasive inability to correctly assess their bench height in relationship to their normal or preferred bench height was unexpectedly poor. Seeking to understand the data in terms of pianists’ joint position sense, we re-examined the data using a ±5° tolerance. With this tolerance, only 7 errors in bench height identification remained out of the 60 responses (Table 7). These results suggest that the subjects’ ability to discriminate between forearm angles is precise to within approximately 5°; however, it is unknown whether this limited perceptual threshold presents a problem for pianists. The perception errors which persisted despite the ±5° tolerance range were confined to only five subjects. Of these, one had selected an outlier bench height, and all but one had experienced multi-site episodes of playing-related pain.

Table 7: Joint Position Perception

<table>
<thead>
<tr>
<th></th>
<th>+10°</th>
<th>-10°</th>
<th>0°</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Responses</td>
<td>17</td>
<td>15</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Correct Within ±5° Tolerance</td>
<td>18</td>
<td>18</td>
<td>17</td>
<td>-</td>
</tr>
</tbody>
</table>

Although subjects were very opinionated about the effect of each bench height variation on their playing, they were often wrong in their assessment of the position in comparison to their preferred or typical playing position. Further, the differences in muscle activation between forearm orientations were not statistically significant. This indicates a previously unrecognized mismatch between pianists’ perceptions and the physical realities of their playing. Developing a better understanding and awareness of the physicality of playing may assist pianists to both perform better and to avoid injuries.
Limitations

The population size of the study resulted in relatively low statistical power, making Type I errors more likely. In Type I errors, the null hypothesis is incorrectly rejected. Identification of trends all the trends in the data could have been limited by the study’s population size.

Although some subjects were expert sight-readers and gave consistent performances of the sight-reading piece, others appeared to improve their playing of the excerpt with each trial. This may be evidence of a learning effect in their performance quality across the four trials using the sight-reading piece that could have altered their muscle activation patterns in the successive bench height adjustments, even though bench height order was randomly assigned for each subject.

Future Work

The large amount of data collected in this study can be partitioned and analyzed further. The results presented in this thesis are an accurate summation of the most general trends of the data, but further trends remain to be identified and understood. For example, sEMG data can be partitioned by dominant vs. non-dominant side instead of the left-right partition used for this analysis. Although it was not the initial purpose of the study, data were also captured about the effects of different playing tasks on muscle activation, and trends in that data can be explored. Further, data from the sight-reading task can also be assessed. Less skilled sight-readers exhibited subjectively improved performances throughout the four bench heights examined, and trends in muscle activation may exist in those data.
The study could be repeated with a larger enrollment to further explore trends in
the data that may have been masked by the enrollment of the study this far. A prepared
piece, the same across all subjects, could also be added, with the goal of assessing the
same motions across all subjects without the differences between trials that could have
been caused by learning the sight-reading piece throughout the course of the trials.

The study’s methodology is based on the methods of other relevant studies, but
expands beyond them. The methods developed here can be used to investigate more
research topics that have not previously been considered. These could include
investigating other postural aspects of playing the piano, such as distance of the bench
from the piano. The methods could also be used to investigate the merits of different
schools of technique in maximizing efficiency for specific motions.

This study has also opened inquiry into the area of joint angle perception in
pianists. A study designed specifically to investigate this question could shed light on
pianists’ development of joint angle perception throughout their training and any
differences between pianists’ joint angle perception and the joint angle perception of non-
musicians. Other joints important to posture at the piano could also be assessed, including
the shoulders and back.

Future studies could explore the impact of bench height variation on sound
production. While this study acquired information on pianists’ perceptions of the effect of
bench height variation on their playing, it was not designed to evaluate accuracy and
performance quality objectively. A study could be designed to investigate the impact of
different bench heights on pianists’ performances, and could also investigate their ability
to assess their own performances at different bench heights.
Conclusion

This study utilized surface electromyography, body-worn sensors, and a research questionnaire to investigate the effects of bench height variation on pianists’ muscle activation and experience of different bench heights. We discovered that bench height variation did not produce statistically significant changes in muscle activation across subjects, contrary to the previous understanding of both piano pedagogues and arts medicine practitioners. We also found that pianists were opinionated about the impacts of the different bench heights on their playing, but they were not consistently able to identify bench heights in relationship to the bench height at which they typically practice and perform. However, their ability to correctly identify bench heights with a ±5° tolerance suggests that pianists’ joint position sense for the elbow joint is precise to approximately 5°.

After analysis, the data suggest that either (1) no single bench height minimizes muscle activation across pianists, or (2) bench height does not affect muscle activation. Further studies can investigate these two possibilities. The combination of a lack of identifiable impact of bench height variation on muscle activation with pianists’ inability to correctly identify the bench height in comparison to other bench heights suggests that pianists experience a fundamental disconnect between their perception of their playing and the physicality of their playing.
REFERENCES


APPENDICES

A - IRB Approval
B - Consent Forms
C - Research Questionnaire
D - Five-Finger Pattern
E - Sight Reading Excerpt
APPENDIX A: IRB APPROVAL

The following research study has been approved by the Institutional Review Board at Ohio University for the period listed below. This review was conducted through an expedited review procedure as defined in the federal regulations as Category(ies): 4 6 7

**Project Title:** Effects of Bench Height Variation on Muscle Activity in Pianists

**Primary Investigator:** Sarah E. Welch

**Co-investigator(s):** Jeffrey Russell

**Faculty Advisor:** Christopher Fisher

**Department:** Honors Tutorial College

**Robin Stack**
Robin Stack, CIP, Human Subjects Research Coordinator
Office of Research Compliance

**Approval Date:** March 7, 2014

**Expiration Date:** March 6, 2015

This approval is valid until expiration date listed above. If you wish to continue beyond expiration date, you must submit a periodic review application and obtain approval prior to continuation.

Adverse events must be reported to the IRB promptly, within 5 working days of the occurrence.

The approval remains in effect provided the study is conducted exactly as described in your application for review. Any additions or modifications to the project must be approved by the IRB (as an amendment) prior to implementation.
The amendment, detailed below, and submitted for the following research study has been approved by the Institutional Review Board at Ohio University.

**Project:** Effects of Bench Height Variation on Muscle Activity in Pianists

**Amendment:** Use 3 measuring methods; Use new SEMG equipment; Add E. Chou as Co-investigator; Test with only 4 bench heights.

**Primary Investigator** Sarah E. Welch  
**Co-Investigator(s):** Jeffrey Russell  
Esther Chou

**Advisor:** Christopher Fisher  
(if applicable)

**Department:** Honors Tutorial College

Robin Stack, CIP, Human Subjects Research Coordinator  
Office of Research Compliance

**Protocol Expiration Date:** 3/6/2015
The amendment, detailed below, and submitted for the following research study has been approved by the Institutional Review Board at Ohio University.

Project: Effects of Bench Height Variation on Muscle Activity in Pianists

Amendment: Add 2 inertial measurement units; Add maximum voluntary contraction measurement.

Primary Investigator  Sarah E. Welch
Co-Investigator(s): Jeffrey Russell
                      Esther Chou

Advisor: Christopher Fisher

Department: Honors Tutorial College

Robin Stack, CIP, Human Subjects Research Coordinator
Office of Research Compliance

Protocol Expiration Date: 3/6/2015

Date: Oct. 24, 2014
The following research study has been reviewed and approved by the Institutional Review Board at Ohio University for the period listed below. This review was conducted through an expedited review procedure as defined in the federal regulations as Category(ies):  

Project Title: Effects of Bench Height Variation on Muscle Activity in Pianists

Primary Investigator: Sarah E. Welch
Co-Investigator(s): Jeffrey Russell, Esther Chou

Faculty Advisor: Christopher Fisher
Department: Honors Tutorial College

Robin Stack, CIP, Human Subjects Research Coordinator
Office of Research Compliance

March 14, 2015
Approval Date
March 15, 2016
Expiration Date

This approval is valid until expiration date listed above. If you wish to continue beyond expiration date, you must submit a periodic review application and obtain approval prior to continuation.

Adverse events must be reported to the IRB promptly, within 5 working days of the occurrence.

The approval remains in effect provided the study is conducted exactly as described in your application for review. Any additions or modifications to the project must be approved by the IRB (as an amendment) prior to implementation.
APPENDIX B: CONSENT FORMS

Ohio University Consent Form

Title of Research: Effects of Bench Height Variation on Muscle Activity in Pianists
Researchers: Sarah Welch, Dr. Christopher Fisher, Dr. Jeffrey Russell

You are being asked to participate in research. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits, in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You will receive a copy of this document to take with you.

Explanation of Study

This study is being done to better understand how bench height variation affects the muscle activity of pianists while playing, and how it affects their perceived experience of playing.

If you agree to participate, you will be asked to let us attach electrodes to your arms and shoulders, after preparing the skin with alcohol prep pads. Before playing, you will be asked to pull against a chain using various positions of your arms so that we can test your muscles’ electrical response during a maximum contraction and see what they do while you play the piano. Following that, while you play, we will record the muscles’ activity during playing, along with audio and video of your playing. You will be asked to complete a survey before playing, and to answer two additional questions at each bench height tested.

Your participation in the study will last for 30-40 minutes. It will consist of playing two short passages (less than 60 seconds each) at four different bench heights while data is recorded, and answering the questions on the survey. A small device to measure the angle of your forearm from the horizontal will be attached to your forearm with an elastic strap during data collection.

Risks and Discomforts

Risks or discomforts that you might experience are minimal. Removing the adhesive electrodes sometimes irritates the skin around the site. This irritation is minor and temporary, and will go away without need for treatment. We will place the electrodes in a manner that will minimize the risk of discomfort as much as possible.

Benefits

This study is important because many pianists suffer from injuries due to various causes. We hope to better understand the effect of one specific variable, bench height, on muscle activity in pianists while playing, and in their perceived experience of playing. We anticipate that the results of this study will influence pedagogical methods, and may have implications for how playing-related overuse injuries in
pianists are understood by medical professionals and piano teachers.

You might not personally benefit by participating in this study.

**Confidentiality and Records**
No personally identifying information will be collected from you during the course of this study. Your record will be preserved with a unique identifier number ("subject number") which is not associated with your name. Video recording will be conducted, but will not be personally identified or identifiable.

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:
- Federal agencies, such as the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
- Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU.

**Contact Information**
If you have any questions regarding this study, please contact

Sarah Welch  
Junior, Honors Tutorial College, Ohio University  
Phone: 740.818.6755  
Email: sw224511@ohio.edu

Dr. Christopher Fisher  
Chair, Ohio University Keyboard Division  
Phone: 740.593.4233  
Email: fisherc@ohio.edu

If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

By signing below, you are agreeing that:
- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered
- you have been informed of potential risks and they have been explained to your satisfaction.
- you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study
- you are 18 years of age or older
- your participation in this research is completely voluntary
- you may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you and you will not lose any benefits to which you are otherwise entitled.

Signature:_________________________ Date__________________

Printed Name_________________________ Version Date:10/2/14
Ohio University Assent Form

Title of Research: Effects of Bench Height Variation on Muscle Activity in Pianists
Researchers: Sarah Welch, Dr. Christopher Fisher, Dr. Jeffrey Russell

You are being asked to participate in research. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits, in order to make an informed decision. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. You may ask questions at any point while you read this form or after you have read it.

Explanation of Study

This study is being done to better understand how changing pianists’ bench heights affect the way their muscles act, and how they think they sound while playing. If you agree to participate, you will be asked to let us attach adhesive electrodes to your arms and shoulders. Then you will be asked to pull against a chain using various positions of your arms so that we can test your muscles’ activity during a maximum contraction and see what they do while you play the piano. Following that, while you play, we will record the muscles’ activity during playing, along with audio and video of your playing. You will be asked to answer some questions before and after playing. Your participation in the study will last for 30-40 minutes. We will also use an elastic strap to hold a device on your arm which will keep track of your arm’s location.

Risks and Discomforts

Risks or discomforts that you might experience are minimal. Removing the adhesive electrodes sometimes irritates the skin around the site. This irritation is minor and temporary, and will go away without need for treatment. We will place the electrodes to minimize the risk of discomfort as much as possible.

Benefits

This study is important because many pianists suffer from injuries due to various causes. We want to understand how changing bench height affects what your muscles do while you play, and how you perceive your playing. We anticipate that our results will influence how piano teachers teach, and may influence how medical professionals treat pianists who have been injured because of playing. You might not personally benefit by participating in this study.

Confidentiality and Records

We will not collect any personally identifying information from you. Your record will be preserved with a unique identifier number (“subject number”) which is not associated with your name. We will record video, but it will not be personally identified or identifiable.
Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:

* Federal agencies, such as the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU.

By signing below, you are agreeing to participate in research.

Signature: ___________________________ Date ____________

Printed Name __________________________________________

Version Date: 10/2/14
Ohio University Parental Consent Form

Title of Research: Effects of Bench Height Variation on Muscle Activity in Pianists
Researchers: Sarah Welch, Dr. Christopher Fisher, Dr. Jeffrey Russell

Your child is being asked to participate in research. For you to be able to decide whether you want your child to participate in this project, you should understand what the project is about, as well as the possible risks and benefits, in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your child’s personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your child’s participation in this study. You will receive a copy of this document to take with you.

Explanation of Study
This study is being done to better understand how bench height variation affects the muscle activity of pianists while playing, and how it affects their perceived experience of playing.

If you agree to allow your child to participate, he or she will be asked to pull against a chain using various positions of his/her arms so that we can test his/her muscles’ electrical response during a maximum contraction and see what they do while your child plays the piano. Following that, while your child plays, we will record the muscles’ activity during playing, along with audio and video of your child playing. Your child will be asked to complete a survey before playing, and to answer two additional questions at each bench height tested.

Your child’s participation in the study will last for 30-40 minutes. It will consist of playing two short passages (less than 60 seconds each) at four different bench heights while data is recorded, and answering the questions on the survey. A small device to measure the angle of your child’s forearm from the horizontal will be attached to his or her forearm with an elastic strap during data collection.

Risks and Discomforts
Risks or discomforts that your child might experience are minimal. Removing the adhesive electrodes sometimes irritates the skin around the site. This irritation is minor and temporary, and will go away without need for treatment. We will place the electrodes in a manner that will minimize the risk of discomfort as much as possible.

Benefits
This study is important because many pianists suffer from injuries due to various causes. We hope to better understand the effect of one specific variable, bench height, on muscle activity in pianists while playing, and in their perceived experience of playing. We anticipate that the results of this study will influence pedagogical methods, and may have implications for how playing-related overuse injuries in pianists are understood by medical professionals and piano teachers.
You and your child might not personally benefit by participating in this study.

**Confidentiality and Records**

No personally identifying information will be collected from you or your child during the course of this study. Your child’s record will be preserved with a unique identifier number (“subject number”) which is not associated with his or her name. Video recording will be conducted, but will not be personally identified or identifiable.

Additionally, while every effort will be made to keep your child’s study-related information confidential, there may be circumstances where this information must be shared with:

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* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU.

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• you have been informed of potential risks and they have been explained to your satisfaction.
• you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study.
• you are 18 years of age or older.
• your child’s participation in this research is completely voluntary.
• your child may leave the study at any time. If you or your child decide to withdraw participation in the study, there will be no penalty and neither you nor your child will lose any benefits to which you are otherwise entitled.

Parent/Guardian Signature: ________________________ Date ________________

Printed Name ________________________________

Child’s Name ________________________________  Version Date: 10/2/14
APPENDIX C: RESEARCH QUESTIONNAIRE

APPENDIX C

Personal History Questionnaire

Subject Number: ______  Age: ______________

1. How long have you been playing the piano? ___________ years

2. How long have you received piano instruction? ___________ years

3. On average, how much time do you spend playing in a week? The worksheet below will help you to answer this question accurately.

<table>
<thead>
<tr>
<th></th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
</tr>
<tr>
<td></td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
</tr>
<tr>
<td>Rehearsals, classes, lessons, etc.</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
<td>______ hr</td>
</tr>
<tr>
<td></td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
<td>______ min</td>
</tr>
</tbody>
</table>

For the purposes of this questionnaire, “playing-related” means as a direct result of playing the piano.

1. Has an episode of playing-related pain or injury ever caused you to miss one or more rehearsals, lessons, classes, or performance obligations?  □ Yes  □ No

2. How many of these episodes have you experienced?

□ 1-2  □ 3-4  □ 5-6  □ 7+

3. Approximately when did the most recent episode occur?

□ Currently  □ Within the past month
□ Within the past year  □ Within the past five years
4. Where did your pain or injury episode occur? Check all that apply.

☐ finger(s)       ☐ hand       ☐ wrist
☐ forearm         ☐ elbow       ☐ upper arm
☐ shoulder        ☐ neck        ☐ upper back
☐ middle back     ☐ lower back  ☐ lower extremity
☐ other: ________________________________

5. Have you ever visited a physician or other healthcare provider as a result of an episode of playing-related pain or injury?  ☐ Yes  ☐ No

**Please read the statements below and circle your response.**

6. I think bench height is important to reducing the risk of playing-related pain or injury.

Disagree Somewhat disagree Neutral Somewhat agree Agree

7. I pay careful attention to my bench height before and during practice.

Disagree Somewhat disagree Neutral Somewhat agree Agree

8. The height at which I set my bench impacts the sound I produce.

Disagree Somewhat disagree Neutral Somewhat agree Agree

9. I ________ use an adjustable bench in my practice.

Always Often Sometimes Occasionally Never
Research Questionnaire

<table>
<thead>
<tr>
<th>Compared to my normal bench height, Height 1 seems</th>
<th>Does Height 1 impact your playing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The same</td>
<td>Yes, positively.</td>
</tr>
<tr>
<td>Higher</td>
<td>Yes, negatively.</td>
</tr>
<tr>
<td>Lower</td>
<td>No, not at all.</td>
</tr>
<tr>
<td>I don’t know.</td>
<td>I don’t know.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compared to my normal bench height, Height 2 seems</th>
<th>Does Height 2 impact your playing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The same</td>
<td>Yes, positively.</td>
</tr>
<tr>
<td>Higher</td>
<td>Yes, negatively.</td>
</tr>
<tr>
<td>Lower</td>
<td>No, not at all.</td>
</tr>
<tr>
<td>I don’t know.</td>
<td>I don’t know.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compared to my normal bench height, Height 3 seems</th>
<th>Does Height 3 impact your playing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The same</td>
<td>Yes, positively.</td>
</tr>
<tr>
<td>Higher</td>
<td>Yes, negatively.</td>
</tr>
<tr>
<td>Lower</td>
<td>No, not at all.</td>
</tr>
<tr>
<td>I don’t know.</td>
<td>I don’t know.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compared to my normal bench height, Height 4 seems</th>
<th>Does Height 4 impact your playing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The same</td>
<td>Yes, positively.</td>
</tr>
<tr>
<td>Higher</td>
<td>Yes, negatively.</td>
</tr>
<tr>
<td>Lower</td>
<td>No, not at all.</td>
</tr>
<tr>
<td>I don’t know.</td>
<td>I don’t know.</td>
</tr>
</tbody>
</table>
APPENDIX D: FIVE-FINGER PATTERN
APPENDIX E: SIGHT-READING PIECE

Waltz in C Major
Anton Diabelli