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Assessment of Muscle Activity and Joint Angles in Small-Handed Pianists:

A Pilot Study on the 7/8-Sized Keyboard versus the Full-Sized Keyboard

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Abstract—This pilot study examined whether the use of a 7/8 keyboard contributed to the physical ease of small-handed pianists as compared with the conventional piano keyboard. A secondary research question focused on the progression of physical ease in pianists making the transition from one keyboard to the other. For the purposes of this study, a hand span of 8 inches or less was used to define a "small-handed" pianist. The goal was to measure muscle loading and hand span during performance of a specified musical excerpt. For data collection, each of the two participants was connected to an 8-channel electromyography system via surface electrodes, which were attached to the upper back/shoulder, parts of the hand and arm, and masseter muscle of the jaw. Subjects also were fitted with electrogoniometers to capture how the span from the first metacarpophalangeal (MCP) joint to the fifth MCP joint moves according to performance demands, as well as wrist flexion and extension and radial and ulnar deviation. We found that small-handed pianists preferred the smaller keyboard and were able to transition between it and the conventional keyboard. The maximal angle of hand span while playing a difficult piece was about 5° smaller radially and 10° smaller ulnarly for the 7/8 keyboard, leading to perceived ease and better performance as rated by the pianists. *Med Probl Perform Art* 2006;21:3–9.

The technical problems encountered by small-handed pianists are often directly related to the size of the piano keyboard. Other instruments, most notably string instruments, are available in various sizes (i.e., 7/8, 15/16, etc.), primarily for pedagogical reasons. Unfortunately, with the piano keyboard, a "one size fits all" mentality has prevailed. Players having small-sized hands have historically been dedicated amateurs.

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Aside from Wagner's notable study[1] on hand anthropometrics among pianists, writings addressing hand size issues have concerned themselves primarily with suggesting adaptive strategies for small-handed players. For example, Deahl and Wristen[2] described a number of technical issues encountered by small-handed pianists playing the conventional-sized keyboard and suggested coping strategies (including considering adoption of the 7/8-size keyboard).

With the greater numbers of women pursuing professional degrees in piano performance and pedagogy, the rigid historical adherence to the conventional piano keyboard is proving increasingly problematic for small-handed players. The 7/8-sized piano keyboard, which has gained attention during the past 5 years or so, is the most common size among several adaptive-sized piano keyboards manufactured by Steinbuhler & Company (Titusville, PA) and can be fitted into a grand piano in place of the conventional-sized keyboard. This smaller keyboard is built around its own piano action and stack, a mechanism that simply can be slid into a conventional-sized grand piano. The 7/8 keyboard has the same number of keys as the conventional keyboard but is roughly 7 inches shorter in total length. The result is that an octave as played on the 7/8 piano keyboard is approximately the width of a white key shorter than an octave as played on a conventional keyboard (Figure 1).

Leone[3] offered empirical evidence that small-handed players had great success with the 7/8-sized keyboard during a trial at Southern Methodist University. However, her findings have not yet been scientifically validated. Measuring movement at the piano is not a novel idea. Several studies have examined pianists' movements in response to growing concerns about the almost epidemic numbers of musicians who experience injury directly related to participation in music-making activities. Pianists, in particular, fall prey to music-related injuries at alarming rates. Among musicians seeking treatment for music-related injury each year, more than half are keyboard players.[4]

In recent years, the sciences of ergonomics and biomechanics have had a continuing impact upon how we view the human body. These sciences focus on finding efficient movements that minimize strain on body tissues and structures. Studies of this nature have contributed to a growing understanding of how the human body interacts with the piano.

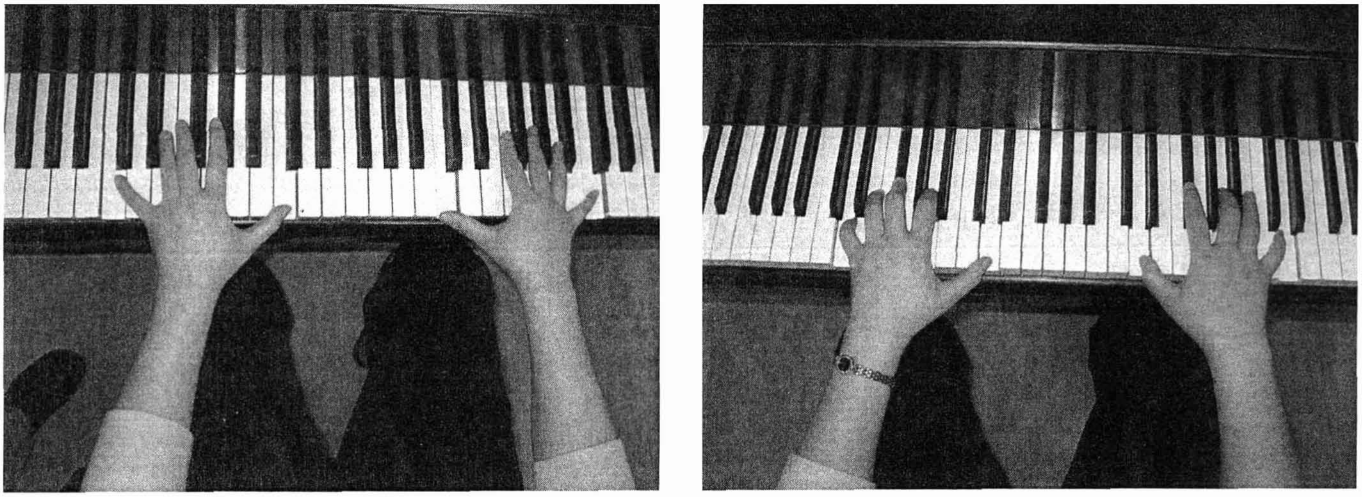

FIGURE 1. Subject playing an octave on the conventional piano keyboard (*left*) and the 7/8 piano keyboard (*right*).

There have already been several studies published that examined motions employed at the piano from a biomechanical or ergonomic perspective, with the underlying motivation of preventing injury or playing-related pain. Biomechanical approaches also have been used preventatively to diagnose problematic aspects of playing technique or to improve efficiency of healthy technique.

Previous studies examining pianists' motions have typically concentrated on one small part of the anatomy or one clearly defined technical motion, often addressing occurrence of injury or pain correlated with this anatomical area or motion. For example, Chung et al.[5] measured average range of motion of the wrist in various playing activities. Harding et al.[6] investigated the relationship between joint and tendon use and distribution of force while playing. Parlitz, Pechel, and Altenmüller[7] developed a unique methodology, using a force-sensing matrix foil that could be slid underneath the keys, to measure forces exerted by pianists upon the keys. In comparing expert pianists with amateurs, they found that experts use considerably less force than amateurs in a task where some fingers were used to sustain notes while other fingers in the same hand were actively playing other notes. In other words, the experts used more efficient motion patterns. These authors further noted that as task complexity was increased and more coordination was demanded from players, both experts and novices reacted by increasing the overall force on the piano keys. Other studies have similarly examined positioning and function of various parts of the body, such as the upper torso, arm, forearm, hand, and fingers. Studies of this nature have contributed to a growing understanding of how the human body interacts with the piano.

Given the concerns that small-handed pianists typically express regarding their ability to cope with typical technical challenges found within the standard advanced piano literature, along with the preference expressed for playing on the 7/8-sized piano keyboard expressed by pianists in Leone's study,[3] the present case study developed a protocol for examining whether the use of the 7/8 keyboard actually contributes to the physical ease of small-handed pianists in comparison with the conventional piano keyboard. Unlike previous studies regarding the 7/8 keyboard, this study employed a scientific method and investigational tools that provide empirical data regarding physical ease. These objective measures were then compared to the more subjective self-perception of ease as expressed by the subjects. Also, pianists who have been presented with the option of performing on the 7/8 keyboard have anecdotally expressed a concern about the amount of time needed to adapt to the smaller keyboard; the present study also examined the learning curve in terms of time and physical ease in transitioning from the conventional keyboard to the 7/8 keyboard and vice versa. The applicability of this transition curve is furthered by the reality that in the real world of piano performance, it is likely that even if pianists elected to practice and perform primarily on the 7/8 keyboard, small-handed players would have to continue to play the conventional-sized on occasion.

Electrogoniometers, or electronic joint-angle sensors, were used in this case study to record joint motion in multiple planes. The placement of twin-axis goniometers on the subjects' left and right wrists to measure extension, flexion, and deviation made it possible to analyze extreme and risky hand/wrist use during playing. Surface electromyography (sEMG), involving placement of electrodes on the skin overlying the muscle, is a convenient, noninvasive method, to measure muscle activity/load or muscle fatigue under different conditions and was utilized in the present study. It should also be noted that sEMG is typically used to evaluate light, repetitive tasks, where activity of specific muscles are of interest, according to NIOSH.[8] Electrode positions for recording myoelectric signals were based on the recommendations and experience of Zipp[9] and reflect positions that have proven satisfactory in past ergonomic research. A measure of the power of muscle force was provided by the root-mean-square (RMS) value of a myoelectric signal that measured muscle strength. DeVries[10] determined the efficiency of electrical activity as a

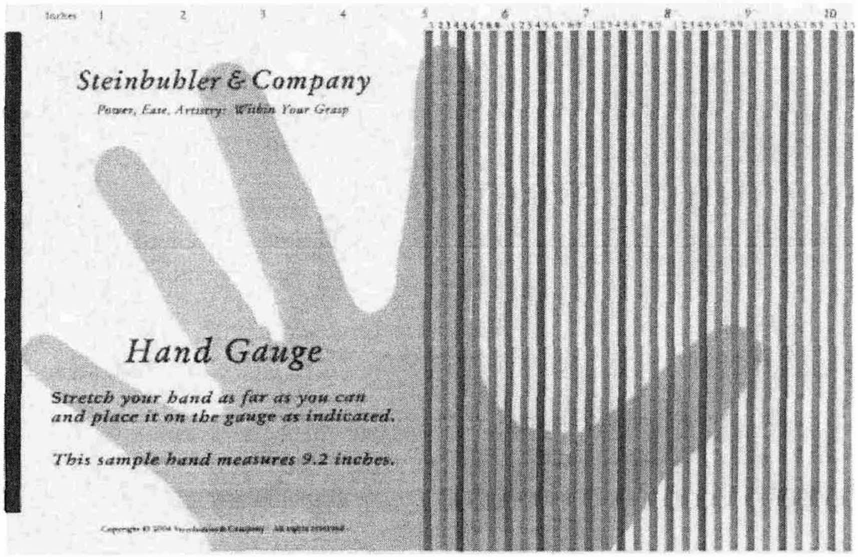

FIGURE 2. Steinbuhler's Hand Gauge (© Steinbuhler & Company, Titusville, PA; used by permission.)

physiologic measure of the functional state of muscle tissue, using the RMS values as an indication of myoelectric activity. The force and RMS values are linearly related, but the slopes of the lines differ for different subject strengths, and therefore, these signals are typically calibrated for each subject, as was done in this case study.

sEMG has been applied previously to the study of musicians' muscular exertions. This type of sEMG measures muscular contraction via surface electrodes pasted onto the skin surface. To date, surface EMG has been used primarily as a means of providing biofeedback to musicians so that they can become aware of and learn to control the level of muscular tension in various parts of their bodies. A literature review by Martens[11] in 1971 suggested that decreasing unnecessary muscle tension should lead to improved performance. With the emergence of readily available sEMG technology, musicians are increasingly interested in using it to help maximize muscular effort.

Morasky, Reynolds, and Clarke,[12] in a 1981 study, examined this premise in string players. They used EMG biofeedback to help string players learn to reduce tension in their left arm, which string players use to hold and finger their instruments. Unfortunately, the authors had to rely on judgments made by the participants regarding the quality of the performance. They followed up these initial results with a 1983 study[13] of clarinetists, demonstrating that the effects of EMG biofeedback could be retained and generalized, not only to performance immediately following the feedback, but also to performances after a period of practice had passed.

In their 2004 case study, Zinn and Zinn's [14] similarly used biofeedback to alleviate playing-related pain in a pianist. These types of biofeedback studies have furthermore addressed the interaction of muscular activity with muscular inhibition. Each muscle has an opposing muscle—muscles are more efficient when simultaneous activation of opposing muscles is avoided.

In addition to studies employing sEMG for biofeedback, sEMG recently has been used in conjunction with other instruments to elucidate motions made by musicians while performing. Shan et al.[15] used motion-capture technology and sEMG along with biomechanical modeling to describe movements made by violinists while playing. Their findings demonstrated how information from multiple modes of assessment, including sEMG, high-speed motion-capture technology, internal load analysis, and biomechanical modeling, could provide a fuller understanding of violinists' interaction with their instruments. The present pilot study used sEMG to identify and quantify muscular exertion in a specific task execution.

METHODS

Subjects

Two small-handed, expert pianists (both female) were invited to participate in this pilot study. David Steinbuhler, inventor of the 7/8 keyboard and owner of D.S. Keyboards (Titusville, PA), has developed a suggested range of hand sizes for the 7/8 keyboard through anecdotal experience. In order to test the accuracy of his recommendations, we chose the midpoint of his suggested 7/8-keyboard hand-size range, 8 inches (22 cm), as the cut off point for inclusion in this study. Once small-handedness was established using Steinbuhler's hand gauge (22-cm full-hand abduction or less is defined as small-handed; Figure 2), hand size also was measured with GPM anthropometers, and this value compared to Steinbuhler's hand gauge size to confirm that the subjects met the criterion of having a total abduction of 8 in or less from the tip of the fifth finger to the top of the thumb while the hand was fully abducted.

Each subject was assigned a primary keyboard on which to practice a musical excerpt. One was assigned the conventional

FIGURE 3. Placement of data collection instruments is shown on the hands and arms of one researcher.

(full) keyboard, and the other the 7/8 (small) keyboard. Each subject was instructed to complete the specified practice hours *only* on the instrument to which she had been assigned. After completing all trials at the assigned keyboard and the "unfamiliar" keyboard, each subject was asked about her practice experience on the assigned instrument, about history of piano-related upper-limb injury, and preference for keyboard size.

Apparatus

During data collection, electrodes and electrogoniometers were placed on each subject, as shown in Figure 3. Each subject was connected to an eight-channel sEMG system (Biometrics, Ltd. Cwmfelinach, Gwent, UK), which measures muscular exertion via surface electrodes. These bipolar electrodes (model SX230) were attached bilaterally to the upper trapezius and to forearm flexors and extensors using disposable sticky collars, following the specific muscle location recommendations of Zipp.[9] Electrodes also were placed on the masseter muscle of the jaw, a frequent site of tension when other parts of the body are inordinately stressed. The goal was to measure muscle loading on the small-handed pianist during performance of a stressful musical excerpt, chosen for inclusion of large chords requiring the subject to play with full hand extension at maximum volume.

Subjects also were fitted with electrogoniometers (Biometrics, Ltd.) to measure the range of motion of the hand span. To accomplish this objective, goniometers (F35, SG65) were placed on base of the hand to the first phalanx of the thumb and fifth finger. A goniometer was also placed on the distal forearm, stretching across the wrist and attached to the dorsal hand. This placement of goniometers allowed for capture of data showing flexion/extension and radial/ulnar deviation at the wrist and conformed to the recommendations specified in the Biometrics Operating Manual.[16] All electrodes and goniometers were calibrated for each subject.

Procedure

Prior to the test session, each subject was assigned the first 1.5 minutes of the Tchaikovsky Piano Concerto in B-flat Minor, Opus 23 to practice on either the conventional/full-scale keyboard or the 7/8 keyboard. They were to practice a maximum of 10 hrs on the excerpt. This excerpt consists of passages of large chords covering the full range of the keyboard, which are difficult for the small-handed pianist due to the great span of hand abduction throughout, with few opportunities to return the hand to its anatomically neutral position. Due to the necessity to locate chords in many registers of the keyboard, the selected excerpt also presented a potentially disorienting visual challenge for the subjects, as they looked at their hands in relation to the keys on the conventional versus the 7/8-size keyboards.

After informed consent and the attachment and calibration of the electrogoniometers and sEMG sensors to determine each subject's maximum voluntary exertion, each subject was asked to play an octave in order to serve as both a reference for the hand span of each subject and, secondarily, as a validation of the average hand span for each of the pianos. Each subject was then asked to complete three trials of the excerpt on the instrument she practiced on, either the 7/8 or conventional piano keyboard. After each trial, the subject was asked to rate her comfort from 1 to 10. The subject was allowed to choose her best trial, which was then correlated with expert assessment to determine best performance. Trials were also tape-recorded for independent verification of best performance. The sEMG and electrogoniometer data were recorded at 1000 Hz for later analysis.

Because the amount of time required to adapt to the 7/8 keyboard from the conventional piano keyboard and vice versa was also of interest, after initial performance of the excerpt on the instrument practiced, each subject was then asked to transition to the other keyboard on which she did not practice (either the 7/8 or conventional-sized keyboard). Subjects played for a total period of 30 min on the unfamiliar keyboard, with performances of the excerpt every 5 min. These multiple performances of the excerpt were interspersed with playing other repertoire of the participant's choosing to reduce any fatigue that might have resulted from the participant's simply playing the excerpt repeatedly and to allow them to adapt to the "unfamiliar keyboard" using more familiar repertoire. During these transitional performances of the excerpt, electrogoniometry and sEMG were recorded. Additionally, after each performance of the repertoire, the subject was asked to rate her level of ease and perceived mastery of the excerpt on a Likert-type scale of 1 to 10.

Experimental Design

The dependent variables of subjective ratings by subject and expert rater, as well as the objective measures of maximum joint angle and average maximum voluntary exertion (MVE%), were subjected to several analyses. Performance of the excerpt on the assigned keyboard was examined with

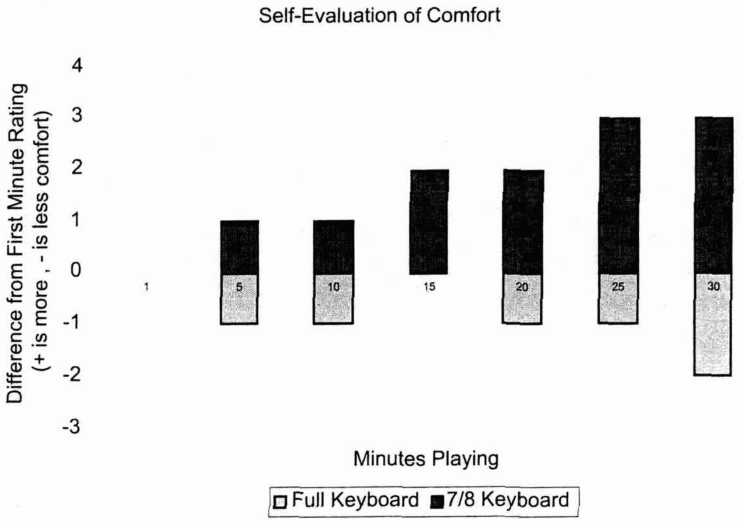

FIGURE 4. Differences in subject's perceived comfort levels when transitioning to the unfamiliar keyboard.

regard to: 1) ease of performance and perceived mastery on a Likert-type scale of 1 to 10, as correlated with expert assessment ratings to determine the best trial; 2) average joint angles over all trials of the excerpt by body location; and 3) sEMG data. Root-mean-square (RMS) of sEMG data was converted to force measurement (*N*) via personal calibration using the resting sEMG and MVE% data previously collected through use of static weights and regression analysis. All data were analyzed using descriptive statistics. These measures were further subjected to analysis of covariance (ANCOVA) on the mean using the covariate of hand span size.

For each subject, the transition to the unfamiliar keyboard (i.e., the keyboard that the subject did not practice on) was examined descriptively for both subject and expert ratings by time. For the transition trials, the following data were collected: 1) the ease of performance and perceived mastery, again confirmed by expert assessment rating to determine best trial; 2) the "comfort level," a 1 to 10 Likert-type measure of a combination of performance execution and physical ease; 3) the average joint angles over all excerpt trials by body location; and 4) RMS for the sEMG, which were converted to force measurement (*N*) via personal calibration using resting sEMG, static weights, and a regression analysis. All data were analyzed using descriptive statistics to examine the shape of the learning or adaptation curve.

Subjects completed seven transition trials spaced 5 min apart on the unfamiliar instrument. The subject's initial transitional performance of the excerpt was normalized to zero, and subsequent transition performance trial data were plotted to determine the shape of the learning or adaptation curve. Transition trials also were subjected to ANCOVA on the mean using the independent variables of time (seven trials) and employing the covariate of hand span size, with maximum and average joint angles and MVE% over the excerpt serving as the dependent variables. The percentage of time that joint angles were outside anatomic neutral and MVE% was >30% of each subject's maximum was calculated by keyboard size. Finally, each subject's self-perceived comfort ratings and the transitional trials and average joint angle and sEMG data across all trials were graphed.

RESULTS

The actual hand size of subject 1 was approximately the 4th percentile for the "digit 3 to wrist crease" length and approximately the 25th percentile in hand breadth; subject 2's hand was approximately the 20th percentile in "digit 3 to wrist crease" length and approximately 3rd percentile in hand breadth when compared to the U.S. Army personnel data.[17]

The subjects' self-reported best performance on both the practice and "unfamiliar" keyboards matched the expert assessment. The difference in their rating (1–10) from their initial rating for the first transition performance of the excerpt is shown in Figure 4, with the self-reported measure from the first transition trial serving as the baseline (0). Figure 5 shows average joint angles bilaterally for each subject across all trials.

The average radial deviation was 5° larger and ulnar deviation was 10° larger for the full-sized keyboard than for the 7/8 (smaller) keyboard. The sEMG data by right and left side of the body for both subjects was converted to muscular force and plotted in Figure 6. The force exertions for the full and 7/8 keyboards are shown in Figure 6. Both the average angle (degrees) and average force (*N*, as calculated from RMS EMG) were plotted bilaterally for each subject.

DISCUSSION

From these data, we can show that for these two small-handed pianists, the 7/8 keyboard was preferred using subjective measures. These findings were substantiated by the expert rating for both missed keys (incorrect pitch) and pauses during performance, as well as by the range of hand span required to play the excerpt. The divergence of the

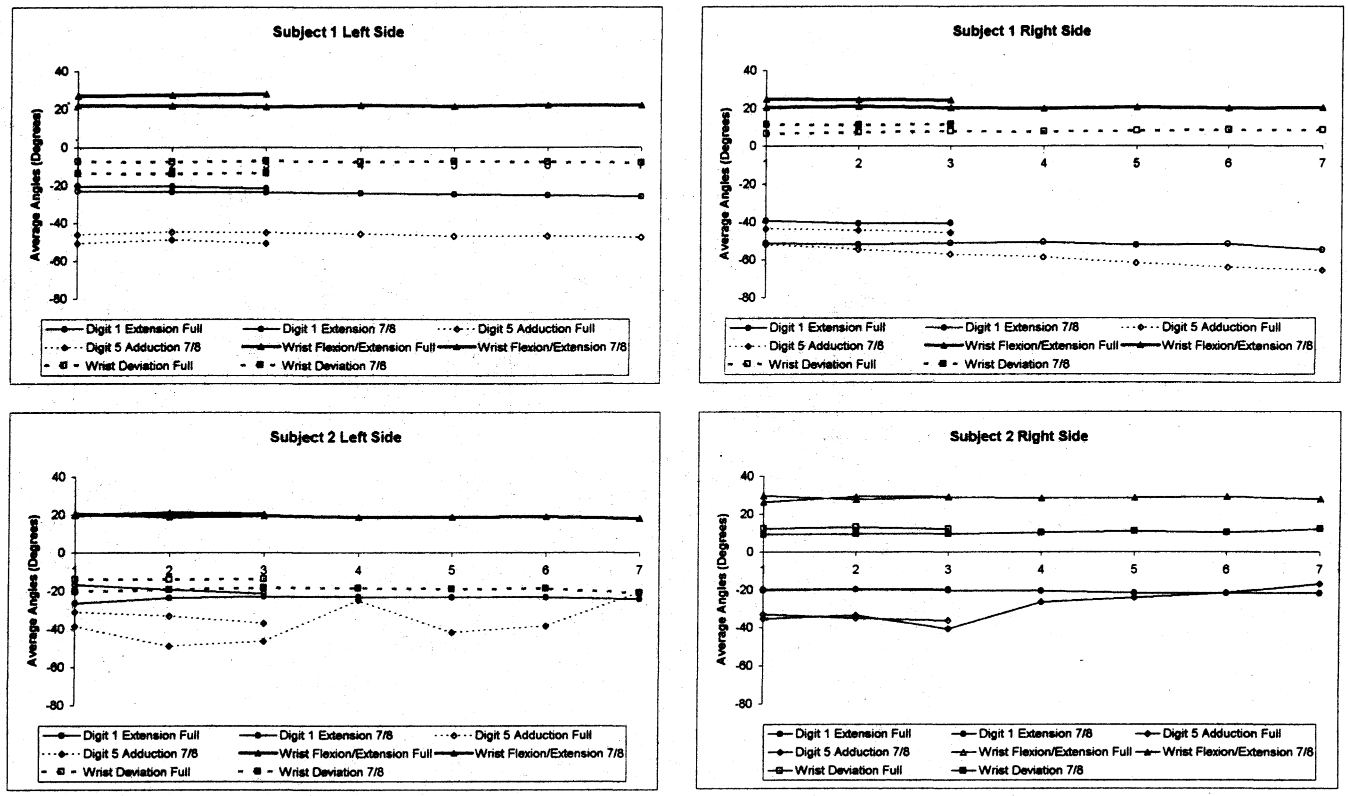

FIGURE 5. Average angles by trial for subject 1 (*top row*) and subject 2 (*bottom row*).

"comfort level" as rated by the participants shows that on the full-sized piano, the comfort level went down, whereas the 7/8 piano became more comfortable as the subject continued to accommodate to the smaller keys.

It is notable that initially subject 1, who practiced on the 7/8 keyboard, rated her first transitional trial at the conventional keyboard as a 6 on the 10-point scale. This rating makes sense, as the subject had been playing for many years on the conventional piano prior to the study. However, in subsequent transition trials on the conventional keyboard, subject 1's self-perceived comfort levels decreased. Subject 2 expressed a lower starting value when transitioning to the 7/8 keyboard, likely because it was her first encounter with the smaller keyboard. However, it is notable that her subsequent transition trial comfort ratings were progressively higher.

On average, the difference in the amount of stretch or the maximal hand span for the small-handed pianists was 15° on the 7/8 keyboard as compared to the conventional keyboard. The average joint angles for the smaller (7/8) keyboard were smaller overall than those employed in playing the full-sized keyboard. The forces for the subjects were about the same for the two keyboards, except for subject 2 on her right side. A likely explanation for this observation is that subject 2 demonstrated a consistently high degree of wrist flexion when playing the octave. This extreme flexion is most likely an adaptive response to the demands of reaching the octave on a full-sized keyboard with a small hand. While this hand position is awkward and not recommended, playing an octave using an extreme degree of wrist flexion permits a slightly larger span between the tips of the thumb and fifth finger, as long as the palm is held up and away from the keys. Thus, many small-handed players unconsciously make this unfortunate accommodation in hand use when playing octaves.

Subject 2 used the same high degree of wrist flexion while playing the octave on the 7/8 keyboard, even though this adaptive strategy was not necessary on the smaller keyboard. The subject used this high degree of wrist flexion throughout her performances on all trials at both instruments, likely because it was an ingrained habit. Unfortunately, this flexion at the wrist prevented accurate angle measurement for both radial and ulnar deviation.

Both subjects performed the excerpt using printed music, which complicated the physical execution of the excerpt since the subjects had to look up to read the score and look down to position their hands correctly. The performance excerpt, selected from the opening of the Tchaikovsky Piano Concerto in B-flat Minor, employs large chords that shift over a wide range of the keyboard. As previously noted, the performance excerpt is visually challenging as is, without the added complication of looking up at the music and down at the hands. Based on this observation, we decided to require that subjects memorize the excerpt in the future studies investigating the efficacy of the 7/8 piano keyboard.

The findings regarding joint angle and force loading as measured in this pilot study suggest that reduction in the size of the keyboard for the small-handed pianist will lead to easier, more enjoyable practice and performance. This

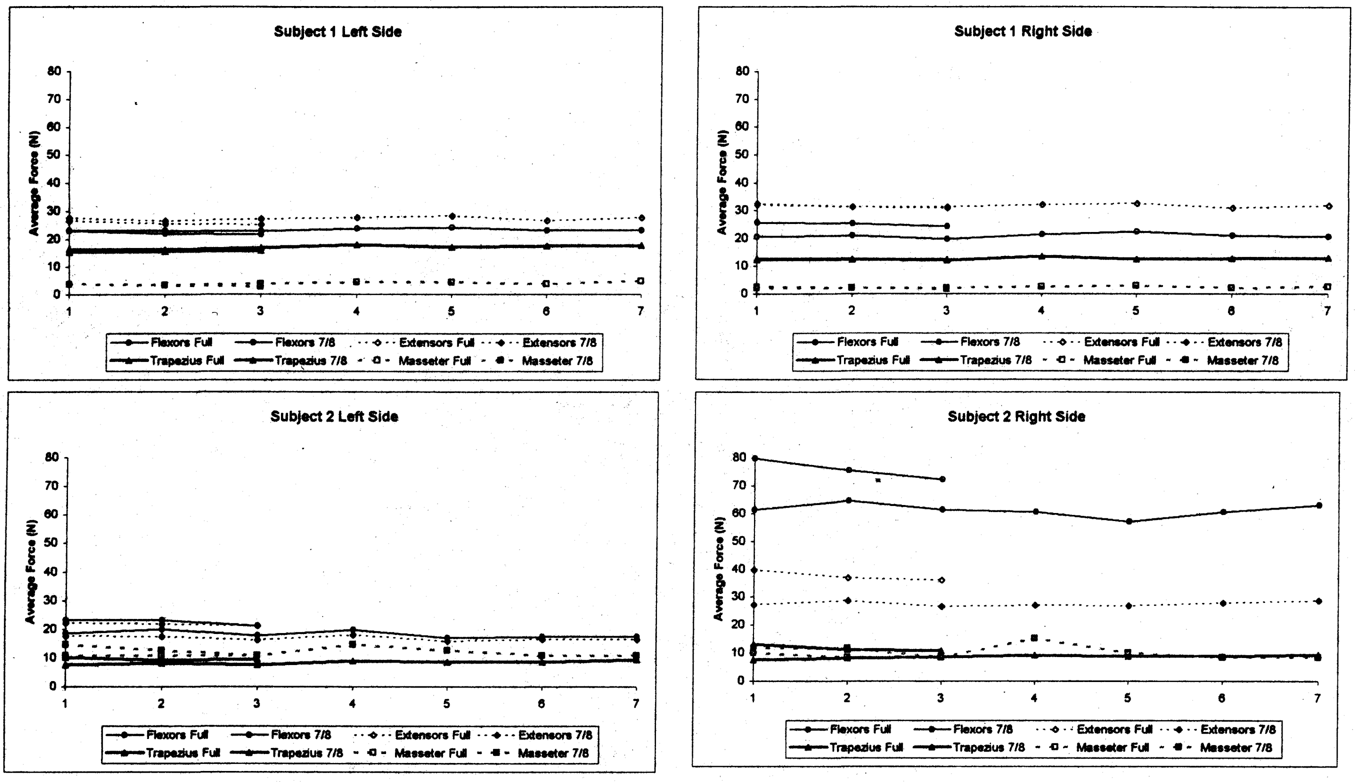

FIGURE 6. Average force (from sEMG) by trial for subject 1 (*top row*) and subject 2 (*bottom row*).

hypothesis will be more fully investigated in a larger subsequent study. This second study will employ both expert and novice small-handed pianists as subjects, thus allowing for generalization of findings across levels of pianistic experience. The same data will be collected; however, with the larger research population, power statistical analyses can be performed and more concrete conclusions can be formed.

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