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Assessing Injury Risk In Pianists

Using Objective Measures To Promote Self-Awareness

Providing students with feedback is an essential and crucial part of a piano lesson. As piano teachers, most of us have been in a situation in which our student responds to our feedback with a surprised look and the question: "Was I really doing that?" We are not sure whether to attribute the student's response to his lack of careful listening, a lapse in concentration, poor kinesthetic sense or, even worse, our own judgment.

Our research team, consisting of a pianist, two computer engineers and a physical therapist, sought to investigate how pianists perceive their hand positions at the keyboard versus how a novel objective tool, in this case an application for the Microsoft Kinect Depth Camera, compiles that information. Furthermore, we wanted to examine how such objective evaluation through visual feedback could potentially assist in the process of developing healthful piano technique and by extension, prevent injury caused by poor hand alignment. The purpose of this article is to discuss a study investigating how the Kinect depth camera could be used to provide visual feedback on pianists' hand postures and, based on the results, suggest strategies for improving students' self-aware-

ness of their technique at the keyboard.

Injury prevention for pianists in recent years has become a concern both among teachers and medical professionals. Playing-related musculoskeletal disorders (PRMD) have a significant incidence in youth, collegiate and professional pianists.[1] A recent study by Bruno Savino, Lorusso Antonio and Nicola L'Abbate found that of 195 youth and adult students surveyed, nearly 40 percent reported disabling PRMDs. Similarly, another survey cited in the *Journal of Music Performance Research* showed that of 505 respondents, nearly 72 percent of professional musicians and 38 percent of non-professional musicians reported PRMDs.[2] PRMDs and overuse disorders commonly include neck pain, shoulder pain, nerve entrapment, tenosynovitis, lateral and medial epicondylitis, distal tendonitis, and flexor, extensor and intrinsic muscle pain at the wrist and hand.[3]

Kinesthesia is commonly defined as the sense that detects bodily position, weight or movement of muscles, tendons and joints.[4] Several resources have examined the cause of injury among musicians and pianists specifically. The causes of these injuries include repetitive strain, overuse, poor posture, environmental conditions and psychologic-

al stress.[5] The commonality among all the causes is stress, meaning a condition that is outside of what is considered normal. Physiological stress on muscles, joints and ligaments refers to holding or repeatedly using the body in positions that push it to its extremes, beyond what is comfortable. Psychological stress may be caused by performance anxiety, feelings of insecurity or depression.[6] Resources agree that prevention is the key and specific techniques aimed at this will be discussed further in this article.[7]

There are three questions we want to examine in this article. First, how does a pianist's self-reported hand position in a questionnaire compare to his or her actual hand position detected by a markerless motion capture device? Second, is there any correlation between the amount of time spent in neutral wrist/hand positions determined by the Kinect and self-reported previous or current injury? Finally, do advanced-level classical pianists exhibit certain characteristics in their hand- and wrist-playing postures that could be modeled by novice pianists?

Methodology

In this study, we focused on investigating hand postures in both professional and college-level pianists. We collected this data for the development of an injury-prevention tool using markerless motion capture. A total of 14 subjects participated in the study, which was conducted at a large university in the Midwest. Of the 14 participants, 11 were either undergraduate or graduate piano majors and 3 were professional pianists.

Data collection for comparison was performed with two main tools: a questionnaire and a markerless motion capture device. Methods included comparison of subjective and objective data in an attempt to compare pianists' own perception of their playing and their actual playing habits as recorded by the Kinect. For the purpose of the objective data collection, we chose to focus on forearm, wrist and hand movements in this initial work. A survey instrument was developed using several previously cited and well-known,

self-assessment questionnaires for PMRDs in musicians.[8] The purpose of the questionnaire was to collect as much information as possible about the subjects' history and/or current injury status, perception of their own playing and the amount of injury-preventative education previously received.

The questionnaire included open- and closed-ended questions, a visual analog scale, diagrams and photo matching. It was divided into the following categories:

1. General demographic questions about the musician (age, gender)
2. Practicing habits (length of practice, body and hand postures)
3. Wellness questions (any education on injury-prevention and any type of previous or current injury)

Additional information was collected at the conclusion of the questionnaire, which included anthropometric data of length of trunk, shoulder width, proximal arm, forearm, hand length and hand width bilaterally.

The Microsoft Kinect version 1.0 has precedent in the literature for capturing piano playing and desk/office postures alike.[9] An application was developed by the engineers involved in this research for the Kinect to capture postural changes and detect specific joints. This application has been validated to be reliable in comparison to a gold standard Vicon marker system.[10] Comparing the two systems, we collected data of three different hand sizes (small: 17 centimeters, length, 17.5 centimeters stretch width; mid-size: 19.5 centimeters, length, 20.5 centimeters stretch width; large: 20 centimeters length, 22 centimeters stretch width) in all the hand positions we intended to use in the study (neutral, collapsed, deviated, flexed, extended). The agreement between the Vicon and the Kinect systems when categorizing the hand postures as neutral, moderate and severe, was correct on average 94 percent of the time. This gives us confidence that the results from the Kinect show strong correlation to the Vicon.

Benefits of using a markerless motion capture device such as the Kinect versus a marker based system include: 1) It does not require wearing markers on the hand or forearm, which can be obtrusive and reduce the playing ability of the subject. 2) It reduces issues of reliability and time intensity for positioning of markers. 3) The equipment is affordable and portable, meaning that it could be used in a piano studio for detecting the degree of poor postures and the amount of time these are maintained. The Kinect has two cameras. One camera provides color images and the other provides depth sensing (a distance measure is stored for each pixel in the image).[11] The depth image resolution is 640 x 480 at a capture rate of 30 frames per second. We utilized only the depth camera for the Kinect, using the depth images directly to capture specific detail of an individual's hand and wrist motions for the following misaligned postures: wrist flexion, wrist extension, ulnar deviation, radial deviation and collapse (extension of the proximal phalange on the metacarpal). A single Kinect camera was mounted approximately 40 inches above the keyboard, directed downward. More detail on the methodology can be found in our previously described work.[12]

Subjects were asked to complete the questionnaire, undergo anthropometric measurements using a standard tape measure and bony landmarks as identified by a physical therapist, and perform a series of six excerpts that were captured using the Microsoft Kinect depth camera. For the purpose of this article we will focus on the three questions as listed above. The repertoire we used was *Chorale, Op. 68, No. 4* by Robert Schumann.

The initial step in this research study was to analyze frame-by-frame the depth images produced by the Kinect. Through this analysis, we examined the hand movements of the pianists and categorized them according to the hand postures they exhibited in each frame. An algorithm was developed to calculate the features measuring the degree of collapse in knuckles, wrist flexion and extension, and ulnar and radial deviation. First, the hands together with the forearms of the player were segmented out from the Kinect raw depth image. Then the 3D coordinates of landmarks of hand center, wrist center and forearm center were calculated using morphology image processing techniques. Features were extracted from the 3D information of these landmarks for each frame. These quantitative features of the frame sequence were used to analyze the hand movements over the playing time period.

Results
1. How does a pianist's self-reported hand position in a questionnaire compare to their actual hand position detected by a marker-less motion capture device?

In the questionnaire, participants were asked to check the correct photo that shows their current hand position and their past hand position. The images showed hands in flexion, extension, radial and ulnar deviation, collapsed knuckles and neutral hand position (See Figures 2 and 3). Participants could check more than one box for both past and present positions. The participants had 26 present responses and 13 past responses. Of the 26 responses of present hand position, only 3 actually matched up with the present Kinect performance (11 percent accuracy). Table 1 shows a summary of the pianists' self-reported hand positions. There may be several reasons the majority of the pianists were unable to recognize their hand position:
1. Poor kinesthetic awareness
2. Different definition of what a neutral position looks like
3. Difficulty of comparing a photo image with a recording (static versus ever-changing movements in a video)

Of the 13 responses of past hand position, 4 matched up with the present Kinect performance (30 percent accuracy). This shows some of the old habits were still discernable.

Seventy-nine percent of the participants stated they held a good neutral hand position a majority of the present time, yet the Kinect did not determine that any participant spent the majority of their time in neutral. According to the Kinect data, the range of time participants were in neutral position was 0–7.5 percent for the left hand and 0.4–13.2 percent for the right hand.

Position	Present	Past
Flexion	21%	14%
Extension	14%	21%
Ulnar Deviation	36%	7%
Radial Deviation	7%	14%
Collapse	0%	29%
Neutral	79%	7%
Straight fingers (arch too high accompanied by some flexion)	29%	0%

Table 1: Self-reported hand positions for the 14 participants.

To compare the pianists' self-reported positions and the positions detected by the Kinect, we averaged the percentage of time they spend in moderate to extreme positions (See Table 2 for degrees of positions).

	Wrist Flexion (degree)	Wrist Extension (degree)	Ulnar Deviation (degree)	Radial Deviation (degree)	Collapse in Knuckles (ratio)13
Neutral	0 ~ +7	0 ~ -7	0 ~ +15	0 ~ -5	0.9 ~ 1
Moderate	+7 ~ +16	-7 ~ -16	+15 ~ +25	-5 ~ -10	0.7 ~ 0.9
Extreme	> +16	< -16	> +25	> -10	0 ~ 0.7

Table 2: Degree range for hand positions.

The results varied among participants. In some cases, for participants that marked the presence of a certain hand posture in their playing, their response matched up with the Kinect system. For example, participants D, G, H and I, noted that, in their present hand position, ulnar deviation occurs. The results from the Kinect system confirmed this response. These participants spent 79 percent, 65.7 percent, 91 percent and 71.5 percent of the time, respectively, in ulnar deviation while playing the Schumann *Chorale, Op. 68, No.4.*

Multiple participants, however, were not accurate in their assessment of which hand positions are prominent in their current playing. Positions they marked as most prominent in the past were still present in their playing at the time of the study. For example, participants C and F marked collapsing of their knuckles as a past habit. The results showed that they still spent 60 percent and 81.2 percent of the time with a collapsed arch.

Other participants were accurate in identifying which positions were not currently present in their playing. This indicates the position may have caused some pain or inefficiencies, and they worked toward improving their technique. Participants C and D marked wrist extension as a position that was present in their playing in the past. The Kinect system confirmed they spent only 3.5 percent and 1.85 percent in those positions.

The information above shows a varied level of correlation between the self-assessment of the pianists past and present report in the questionnaire and the current readings of the Kinect. This brings us to the next important question of the study.

2. Is there any correlation between the amount of time spent in neutral wrist and hand positions and previous or current injury?

One of the questions presented participants with a human figure and asked them to mark on the body areas where they are currently experiencing or have experienced discomfort in the past. They were asked to rank the severity of the discomfort in different body parts. These were ranked as follows: 0 (none), 1 (mild), 2 (moderate) and 3 (severe). Subcategories of discomfort included pain, spasms, pins and needles, fatigue, swelling, stiffness and achiness. Fifty-seven percent of the participants reported having previous intensity of pain ranging from moderate to severe. Only 4 of the participants reported they did not experience pain while playing. The percentage of participants reporting they are currently experiencing pain during a practice session was 71 percent. These findings suggest the need to address injury prevention is urgent. It was also noted that 90 percent of those suffering from discomfort used a change in postural playing position to reduce their level of discomfort. Of those 90 percent, half found a reduction in their pain and 30 percent found complete relief of their discomfort with a change in playing posture. One subject had an unclear answer that was omitted from scoring.

The participants who reported the highest total discomfort score, which is defined as a summation of the their scores from 0 to 4 for the subcategories, were participants C, I and N. These subjects reported a total discomfort rating of 19 points, 15 points and 11 points respectively. This was nearly double their counterparts, who reported discomfort at 6 points or less in total (see Table 3). When the average of percent time spent in neutral of the highest reporters of discomfort was calculated, a percentage of 7.9 percent was found. This was compared to 8.1 percent for the individuals reporting a 6 or less on the discomfort score. The median discomfort score was a 5.4 for the 14 subjects. The group was then divided in half, with those who scored a 5 or above (7 subjects reporting greater discomfort) and those who scored a 4 or less (7 subjects reporting less discomfort). The higher discomfort group averaged 9.9 percent of their time in neutral and the group with less discomfort averaged 6.35 percent of their time in neutral. When compared to the subjects' years of piano playing, the higher discomfort group averaged 20 years of experience, while the less discomfort group averaged 21 years of experience. Due to the limited sample size and the above values, we cannot say with strong support that the time spent outside of our determined neutral range related to previous or current injury. We would attribute this finding to our small sample size, a single music piece and the complexity of chronic pain conditions.

Subject	N	I	C	B	J	M	G	K	A	F	D	E	H	L
Discomfort Score	19	15	11	6	6	6	5	4	3	3	0	0	0	0

Table 3: Level of discomfort reported from previous or current injury (summation of scores from 0 to 4 in the self-assessment questionnaire).

3. Do advanced-level classical pianists exhibit certain characteristics in their hand and wrist playing postures that could be modeled by novice pianists?

Three of the pianists who participated in the study were professional pianists. Although the sample size is not large, by analyzing some of the primary features of the professional pianists, we can conclude that professional pianists exhibit certain common characteristics in their playing. With the exception of one student, professional pianists spent more time in a neutral position than student pianists. For professional musicians, the percentage of time in neutral position was between 7.9–13.2 percent for the right hand and 1.9–7.5 percent for the left hand. In 10 of the 11 students, the amount of time spent in neutral position for the right hand was 0.4–10.2 percent and 0–6 percent for the left hand (See Figure 1). Additionally, it was found that of the top 5 players who spent the greatest amount of time in neutral, 4 of these individuals had the highest reported years of playing experience.

The specific musical example we analyzed seemed particularly conducive to ulnar deviation. It is a chordal piece with the chords mostly toward the middle of the keyboard. The results show this was the case because of a high degree of ulnar deviation present consistently through all the participants.

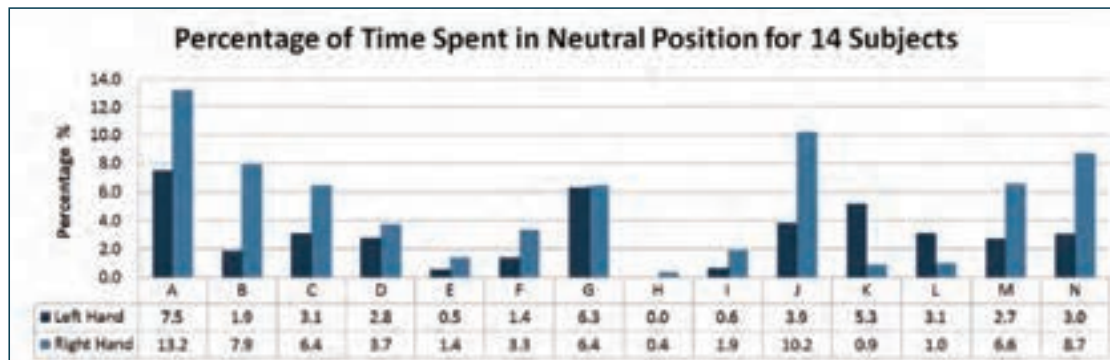| Percentage of Time Spent in Neutral Position for 14 Subjects													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
■ Left Hand	7.5	1.0	3.1	2.8	0.5	1.4	6.3	0.0	0.6	3.9	5.3	3.1	2.7	3.0
■ Right Hand	13.2	7.9	6.4	3.7	1.4	3.3	6.4	0.4	1.9	10.2	0.9	1.0	6.6	8.7

Figure 1: Percentage of time spent in neutral position. Subjects A, B and N are professional pianists.

Based on the information listed above we can conclude that advanced-level pianists and those with the greatest years of experience spent increased time in the neutral range (as defined in Table 2).

Practical Injury-Prevention Tools

As piano teachers, we have the responsibility to educate our students on matters of proper technique and healthy habits. Through this study, we have concrete evidence of the need for multiple approaches to help our students develop a deeper sense of their piano technique through our observations:

1. Using objective means (a video camera or an advanced motion-capturing tool and feedback from the teacher)
2. Self-evaluation of technique
3. Facilitating the development of their kinesthetic awareness.

To these ends, here are some practical suggestions:

Step 1: Observe

Teacher visual observation:

While the student is playing, observe the hand position and notice how frequently it returns to neutral position. Clues that there may be potentially harmful postures present include twisting the hand away from the wrist, "dipping" the hand lower than the key bed or holding the fingers too high, and collapsing the knuckles.

Ask questions:

Engage the student in a conversation to find out what the student thinks his or her hand position looks like. Ask what the hand feels like in specific spots (especially ones that look uncomfortable).

Video-record and observe the recording with the student:

If you have access to video-recording equipment, this would be the time to use it! Record the student performing a piece making sure both hands and torso are in the frame. Watch the recording together and discuss what the student is seeing and your evaluation of arm movements.

Step 2: Identify problems
Avoid extreme positions:

Point to specific spots on the music where you notice extreme positions. If you find those are necessary compensations because, for example, the chords are thick and require stretching, or because the notes are at the extreme ranges of the keyboard and require some twisting, instruct the student to release the poor posture as quickly as possible and return to neutral.

Step 3: Slow, mindful practice to develop kinesthetic awareness

When changing a physical habit, it is important to slow down practice. Our arms move based on self-programmed neuromuscular patterns. In other words, if we are used to collapsing our knuckles when playing a chord and try not to collapse them, it most likely will take considerably more concentration to change the hand shape and to continue to use that new hand shape long-term. Slow practice allows us to tune into our kinesthetic awareness, notice what we are doing and give instructions to our hands and arms to move differently. Over time, this neural pathway becomes solidified, and the new pattern is established.

Step 4: New goals during practice
Return to neutral position frequently:

Foxman and Burgel identify that neutral positions, specifically of arms, fingers and shoulders, must be emphasized.[14] Maintaining and returning to neutral position frequently is key for preventing injury. Often times, that neutral position may not be established, or there might be confusion as to what a neutral position should look and feel like. Based on our observations of professional pianists, neutral position is one in which the wrist is between -7 to +7 degrees of extension and flexion respectively, -5 to +15 degrees of radial and ulnar deviation respectively, and the hand is in a rounded yet relaxed hand shape (not curled). (See Figure 2 for a visual example. Figure 3 shows poor postures to be avoided.)

Figure 2: Neutral position

Collapsed knuckles

Wrist flexion

Wrist extension

Ulnar deviation
Figure 3: Poor hand postures.

Radial Deviation

Recycle muscle use:

Try not to stay in fixed positions that could potentially be harmful. If you notice the hand is staying twisted for an extended period of time, try to analyze whether this is a necessary adjustment. If it is not, reorganize the orientation of the hand to stay closer to neutral. If it is a necessary adjustment, find moments in the music to bring the hand back to a neutral position before returning to a stressed position. A stressed position will likely require excessive use of force. A more natural position can allow the arms to move freely with less force. In Video Examples 1–3 you will see a demonstration of two different ways of playing the same excerpt. In the first part of the recordings the hands are tight with collapsed knuckles and tight wrists. In the second part, the same excerpt is performed with better alignment and releasing of tension between groupings.

Video 1

Video 2

Video 3

Reorganize gestures:

Use large muscle groups whenever possible to alleviate an excessive amount of tension on smaller ones.[15] Organize gestures in terms of the following sequence: Preparation—Attack—Follow-through. We can learn from watching how baseball players swing a bat. First a player twists away to build momentum, then he strikes the ball and releases tension with a forward follow-through. In a pianist's case, the follow-through is usually flexion or an upward movement of the wrists. In the most advanced pianists who participated in our study, flexion was a constant part of the movement pattern. Their movements had a circular quality with each chord instantaneously and consistently followed by a release. This action releases muscular tension, allowing blood, and therefore oxygen, to pump into the muscles, preventing any built-up. In Video Example 4 you can see a demonstration of what this sequence looks like in excerpts that consist of two different textures: First, broken chords (R. Schumann, *Little Study Op. 68, No. 14*) and second chords (R. Schumann, *Chorale Op. 68, No. 4*). The hands are moving continuously in quasi-circular gestures thus generating a preparatory gesture and follow-through gestures after the attack. (See Table 4 for a summary of these suggestions.)

Video 4

Don't:	Do:
Twist the wrist unless absolutely necessary	Use the wrist to guide the fingers
Collapse the arch	Support arm weight on the fingertips
Isolate the fingers	Return to neutral position as frequently as possible
Stay in strained positions for long periods of time	Use the arm and wrist to guide position shifts
	Recycle muscle use
	Reorganize gestures

Table 4: Do's and Don'ts for preventing injury.

Suggestions for further development and limitations

As previously noted, repetitive strain of the neck, mid-back and shoulders is a common problem in PRMDs. The visual field and focus of this study was limited to hand and wrist postures in pianists, but the importance of head position, cervical, thoracic and lumbar alignment must be mentioned. Additionally, there is a need for a neutral pelvic position, as this improves the entire kinematic chain and reduces muscular stress/load throughout the trunk, neck and upper extremities.[16] Previous studies have also shown the relationship between neck and shoulder pain with prolonged sitting postures in adolescents.[17] This continues to reinforce not only proper mechanics at the distal extremity, but also the importance of proper feedback and awareness of the pelvis and spine. Limitations of this study included a limited sample size and only a single selection of music. Further research with a larger sample population and additional pieces of music would be advised.

Conclusions

PRMDs are a significant cause of pain and disability. New innovations and applications utilizing technology could offer novel ways to offer feedback and potentially reduce injury rates. Utilizing such objective measures for capturing poor hand postures and providing feedback to students can potentially reduce the risk of injury. Video recording, as described above, provides students with objective feedback with the goal of improving their self-awareness at the keyboard. The teacher can aid in this process by helping their students observe any habitual holding patterns or extreme positions, and work toward better alignment.

In our study, we have found the Microsoft Kinect offers potential promise for capturing repetitive hand positions during piano playing. This has been compared to a gold standard Vicon motion capture device. We also determined that when comparing our survey with the Kinect output, a significant amount of discrepancy and variability was seen in the subjects' abilities to match their self-reported most common hand position and that captured by the Kinect system. Additionally, we did not see a correlation between subjects reporting decreased current discomfort levels and time spent in neutral as measured by the Kinect. This was a surprise to the investigators, but we believe this was due to the limited sample size and having only one selection of music. Nevertheless, we discovered that 80 percent of those reporting discomfort found some level of relief with postural playing changes focusing on a more neutral position. Finally, we did find commonalities in the playing postures advanced-level classical pianists demonstrate, most notably more time spent in hand/wrist neutral. Future work could include the expansion of the sample size, multiple pieces of music being recorded, and the further development and usage of the Kinect as a feedback tool for subjects at risk or currently diagnosed with a PMRD.

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Notes

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