Human Gesture Quantification: an Evaluation Tool for Somatic Training and Piano Performance

Pierre Payeur,
Gabriel Martins Gomes Nascimento
School of Electrical Engineering
and Computer Science
University of Ottawa
Ottawa, ON, Canada

Jillian Beacon,
Gilles Comeau
School of Music
University of Ottawa
Ottawa, ON, Canada

Ana-Maria Cretu,
Vincent D'Aoust,
Marc-Antoine Charpentier
Computer Science and Engineering
Université du Québec en Outaouais
Québec, QC, Canada

***Abstract*—Motion capture technology has been widely adopted by computer gaming and the movie making industries. The technology also found a suitable niche in some areas of medicine. However, while sports and arts also present important opportunities for analysis of the human gesture, whether to improve performance or prevent injuries, the potential of motion capture was not yet fully exploited in these fields. This paper examines the potential of markerless motion capture in the context of piano pedagogy and performance evaluation when somatic training methods are used. An affordable motion capture platform based on Kinect sensor is designed to suit the specific requirements of piano playing, and an early experimental investigation of the suitability of the technology for this application is reported.**

Keywords—motion capture; human gesture measurement; somatic training; piano performance; Kinect sensor

I. INTRODUCTION

Performing music on a piano requires refined, often fast movement of the arms and hands that changes direction frequently, and demands the coordination of many different muscles and parts of the body simultaneously. In this context, a pianist's posture and the precision of his or her movements can considerably impact the quality of the performance. Furthermore, traditional piano teaching addresses these aspects in a qualitative manner only, and instructors have few pedagogical strategies to assess and improve problematic playing posture and movement. Somatic training methods offer strategies to increase body awareness and improve movement quality, and are therefore of interest to pianists who wish to improve piano technique or remedy movement problems that could contribute to playing-related pain. Unfortunately, the claims that somatic training can result in observable changes in skeletal alignment have not yet been confirmed by research. It remains difficult to quantitatively monitor the actual impact of these innovative training approaches, due to a lack of adapted technologies to measure the movements of a performer with sufficient precision.

In the literature, several solutions have been developed to measure and monitor human gesture in various contexts. Traditional approaches gather information from sensors distributed over the subject's body. As a result, they involve a complex setup and lengthy preparation while imposing important constraints to the movement of the subject. The results are often unreliable or not accurate enough because of the numerous sources of error involved, mutual occlusion between sensors, or difficulty with performing the expected movement. In recent years, solutions have been developed in response to a growing need in medical applications and the movie making industry for accurate recording of human motion. With modern technologies, several cameras are set up to record the movement from several points of view. These views are analyzed and merged to reconstruct the 3D motion.

This paper examines motion capture technologies and adapts one of them to the specific case of measuring piano performer's movement during play. The investigation is conducted in the context of somatic training as a means to improve piano player's performance. A motion capture platform is adapted to the specific requirements of piano performance and its potential as a dedicated tool to assess the impact of somatic training on piano players is experimentally validated.

II. MOTION CAPTURE TECHNOLOGIES

Motion capture is the procedure that collects data from a human or a moving object to evaluate its movement. Numerous marker based systems have been proposed where sensors (e.g. magnetic [1]) or visual markers [2]) are attached on the moving subject, and provide specific points to track. These approaches have the reputation of being cumbersome and relatively complex to operate. Moreover, as markers are attached to the skin or clothes they introduce uncontrolled deviations in the measurement of the actual body movement. Alternatively, markerless approaches eliminate the constraints associated with the use of markers on specific attachment points and open the door to free motion performance and minimal setup requirements [3]. Such systems mainly rely on image sequences from which the motion of a subject, or of multiple subjects, is reconstructed. In order to make the recognition and tracking of an individual possible, most approaches involve a priori known shape models, such as the human body kinematic model, and search for feature correspondences between the acquired views and that model.

As a recently introduced technology, the Microsoft Kinect sensor rapidly found a prominent place as an acquisition platform for human gesture. Kinect is a low-cost, markerless sensor that gathers positional information about the motion of a subject. The fact that it is designed as a human-computer interface for gaming makes it especially suitable to measure human motion, and by extension an individual's performance. The recent literature contains numerous publications that use the sensor for various medical and artistic applications, from rehabilitation and injury risk mitigation to dance performance quantification. Alexiadis *et al.* [4] evaluate dance performance, captured by a Kinect, using a score computed as

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a weighted mean of the joint positions, the joint velocities and 3D error flow of velocity vectors for an amateur dancer versus a professional one. In [5], three Kinect sensors situated around a dancer capture the motion of its feet only, given the specificity of the dance. A fuzzy score is computed based on the knee and angle distance, on the accuracy of the motion with respect to an expert, and on the number of correct motion patterns specific to the dance (choreography score). In the context of quantification of motion for medical assessment and rehabilitation, Lowes *et al*. [6] assess the upper extremity function in individuals with dystrophinopathy using a Kinect platform. The game based on Kinect proposed in [7] elicits specific therapeutic motions when controlling a virtual avatar in order to improve balance in patients. The system of Huang [8] is used for the rehabilitation of young adults with motor impairments. Schonauer *et al.* [9] provide a multimodal input that includes a Kinect motion capture system and bio-signal acquisition devices to a game engine targeting rehabilitation of patients with chronic pain of the lower back and neck.

Several studies also aimed at comparing the performance of Kinect with respect to other motion capture systems [10-12]. Some of these comparisons demonstrated that Kinect is capable to offer a range of disparity that guaranties enough precision in the context of rehabilitation. As well, the Kinect skeletal model was shown to likely offer acceptable accuracy for use as part of a screening tool for injury risk [10]. These studies confirm that the Kinect is an appropriate solution for monitoring piano players with a reasonable precision.

III. Application in Piano Pedagogy

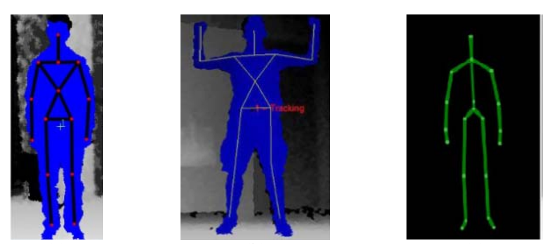
Piano pedagogues and movement specialists hypothesize that the quality of postural alignment while seated at the piano can significantly influence a pianist's ability to produce sound fluently. Pedagogical theories about the etiology of playing-related musculoskeletal disorders (PRMDs) often include posture as a risk factor [13, 14]. Interestingly, recent research on musicians suffering with PRMDs suggests that they have impaired function in the scapular and lumbo-pelvic stabilization systems, which are necessary for maintenance of balanced posture [15]. This evidence indicates that further investigation of the body posture of musicians is warranted. However, thus far, research using 3D motion capture technologies with pianists has focused on quantifying the small, quick movements of the wrist, hand, and fingers [16-21]. Motion-capture studies investigating more holistic body movement of musicians have focused on gaining information about expressive gestures and cuing in ensembles [22-24]. Very little research has employed 3D motion-capture technology to gain a better understanding of postural alignment at the piano, despite the fact that changes in the movement and alignment of the torso and head are slower, and easier to track. To our knowledge, the only study investigating the body alignment of pianists using 3D motion capture technologies is that of Mora *et al*. [25], in which an 8-camera VICON system was used to track the movement and posture of a professional pianist in order to create a 3D model of a well-aligned piano posture for pedagogical purposes.

Due to the association of postural alignment with reliable and sustainable playing technique, many musicians have sought out somatic training methods such as the Alexander Technique [26], the Feldenkrais method [27], or Body Mapping [28], as means to improve technical and expressive control, and postural alignment. Depending on the somatic method employed, practitioners may use therapeutic touch, diagrams, verbal directives, exercises, and manipulation of joints to help individuals reconfigure habits of motor-control that mediate posture. Practitioners seek to heighten kinesthetic awareness and help the brain learn to conceive balance and alignment according to biomechanical principles of the body. Generally, these methods present a holistic image of the body, and approach it as dynamic system without treating isolated muscles or joints. Theories on piano technique that employ principles derived from somatic training methods have appeared in pedagogical literature [29, 30], and many self-help books directed toward musicians mention, or build upon, principles from various somatic methods [31, 32]. Although case studies have been published since the late 1980's reporting dramatic improvements in performance quality and playing-related pain for musicians receiving somatic training, most publications consist of general observations reported by practitioners themselves. The reported benefits of participation in somatic training for musicians have not been confirmed through research. Until now, the main obstacle confronting researchers interested in assessing the impact of somatic training on the posture of pianists is the inaccessibility of reliable tools to quantitatively measure and track changes to body alignment during piano performance.

IV. Human Gesture Quantification System

A. Kinect-based motion quantification

Kinect for Xbox 360 sensor is used in the context of this work due to its price affordability and ease-of-use for operation in a non-traditional environment. Initially, a generic platform for motion quantification, targeting physical exercise monitoring, was developed based on SimpleOpenNI library [33] and supported 15 joints of the human skeleton, as illustrated in Fig. 1a. However, it did not provide measurement for the wrists and hands, which are critical for piano playing. Moreover, a limitation associated with SimpleOpenNI is the fact that the sensor needs to be calibrated before use, using the so-called "psi pose" (Fig. 1b), where the user needs to keep his hands at roughly 90^o and execute a rotation of 360^o. This calibration is undesirable for a pianist who typically sits down.

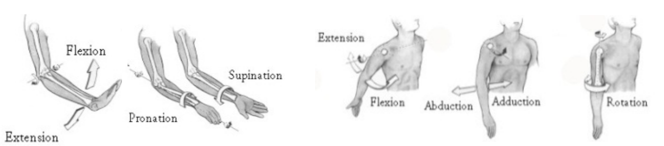


(a) (b) (c)

Fig. 1. (a) Tracked joints and (b) "psi pose" for calibration for SimpleOpenNI and (c) tracked joints under Windows SDK 1.8.

For these reasons, the development of the new acquisition platform was performed using the Kinect for Windows SDK 1.8 (KWSDK) in combination with the Kinect for Xbox 360 sensor, as this library does not require any calibration. The skeleton tracked by the latter also contains 5 more points, associated to the wrists, ankles and an extra point along the spine, as illustrated in Fig. 1c, which ensures a more extensive and accurate description of the motion. Moreover, the KWSDK offers data filtering functions to ameliorate the quality of the tracking results for the skeleton data. Furthermore, the avateering functionality better adapts the collected values to the human physique. This is advantageous because the rotation movement along the *Y* axis (direction of the limbs) cannot be directly tracked. These improvements lead however to a slightly increased response time, but in general, the same speed of 30 frames per second (fps) is reached as with the SimpleOpenNi platform. A limitation associated with the use of the KWSDK with the Kinect for Xbox 360 sensor imposes that the sensor is located far enough from the piano player to ensure the coverage of the upper half of the body within the field of view, while remaining within the operational depth of the sensor.

In order to quantify the motion, the evolution in time of each joint is measured by tracking its corresponding point (*X, Y, Z* coordinates) in the skeleton. The corresponding joint angles are computed using the *AngleBetween()* function from KWSDK and are presented in real-time in the interface for the desired joints. Fig. 2 illustrates the range of motion allowed by human joints at the level of the arms [34], which are of interest for the current application. For the elbow (Fig. 2a), only the flexion and extension can be measured. The rotation of the forearm, along the *Y* axis (supination and pronation) is not a visible feature and cannot be captured, but can be inferred under the Kinect SDK using human joint bio-mechanic constraints. For the shoulder, 2 movements can be measured, one corresponding to extension and flexion, the other one to abduction and adduction. Finally at the level of the wrist, 2 movements are allowed as well. However, the wrist rotation has the origin at the elbow and not at the level of the wrist itself.



(a) (b)

Fig. 2. Human motion characterization at the level of (a) the elbow, and (b) the shoulder [34].

B. Adaptation to piano performance

The Kinect sensor offers a promising solution to the problem of accessible, reliable and unobtrusive motion tracking for assessing the impact of somatic training on posture in the context of piano playing. Researchers have already begun to explore many promising applications for the Kinect and similar 3D markerless motion capture systems in the fields of music pedagogy and performance [35-38]. The possibility of unobtrusive motion capture and analysis of characteristics and timing of gestures during musical performances has important implications for researchers interested in quantifying the movement of performers. The previously mentioned studies which track detailed piano playing movements of the hands employ expensive motion capture systems which track the position of reflective markers fixed to the joints. Although such systems can produce very precise measurements, their use is often impractical due to the high costs and the time consuming process of data preparation and analysis. Furthermore, the necessity of fixing reflective markers to the body can significantly interfere with the participants' ability to perform piano playing movements naturally. Since Kinect sensors do not require the use of markers, pianist subjects may wear comfortable clothing during testing and do not have to perform with cumbersome markers attached to their bodies, allowing for natural performance conditions. Previous research has demonstrated that Kinect sensors can reliably track the position of a pianist's head and arms from a perspective above the keyboard [39, 40]. The software presented here allows for tracking from a vantage point to the side of a seated pianist, allowing for the tracking and measurement of the alignment of the head, shoulders, spine, and hips, which is of a primary concern to somatic trainers. Quantifying the changes in the location of these anatomical positions in space can give valuable information about characteristics of alignment during performance, and offers an important first step toward using markerless motion capture to assess somatic training in the context of piano playing.

The original motion capture platform was modified based on the premise that recording the change of positions of the lower part of the pianist's body would not be required for the purposes of the somatic training evaluation. To meet the requirements of motion capture on piano performers, it is necessary to record the whole set of joints of the upper body simultaneously and save them for further analysis. The Kinect is capable of identifying predetermined points in a human body, which are commonly joints, like the shoulders, the elbows and the wrists. The system uses the information on these joints received from the Kinect to create vectors in a 3D plane which are displayed as points interconnected by orange lines to reproduce the skeleton tracked onscreen, as shown in Fig. 3. These 3D points, measured in meters, are tracked over the sequence of movement and are recorded with timestamps.

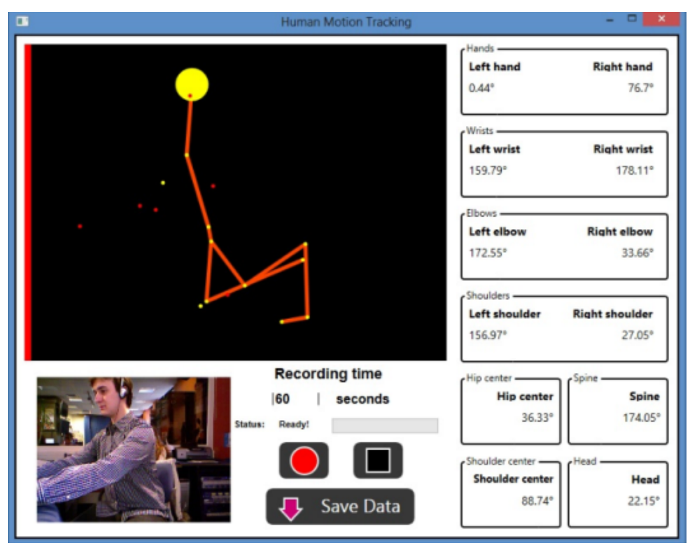


Fig. 3. Human motion tracking program interface.

Joint angles are estimated in between the 3D points marking the joints. A joint angle is calculated using the two lines that connect it to the two neighbor joints along the kinematic chain. Data is exported to a Microsoft Excel workbook that organizes all joints positions and angles with recording timestamps. A five second recording sample is shown in Fig. 4.

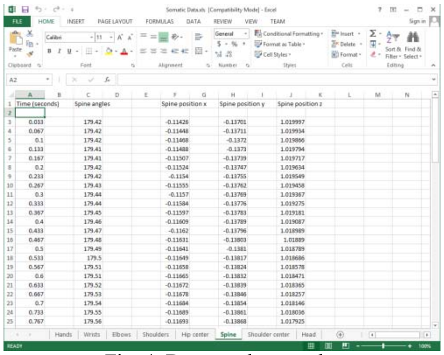


Fig. 4. Data results sample.

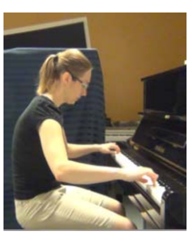
V. Experimental Validation

A. Test scenarios

The experimental setup used consists of one Kinect for Xbox 360 sensor positioned sideways on the right of the piano. along with two video recording cameras, as shown in Fig. 5, that simultaneously collect data to support a separate analysis of posture and movement in 2 dimensions, which is beyond the scope of this paper.

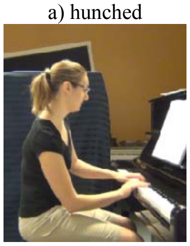
Fig. 5. Picture with piano and Kinect setup.

In order to assess the current ability of the Kinect sensor to track the movement of the head, shoulders, and spine during piano performance, a pianist was tracked playing a 3-octave, contrary motion scale while maintaining a neutral, erect posture.

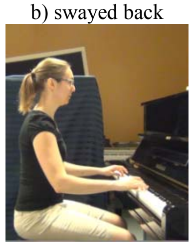


a) hunched

b) swayed back



c) right shoulder lowered



d) baseline straight posture

Fig. 6. Various postures considered for motion capture technology validation.

The pianist was then tracked performing the same playing task again in three different, exaggerated postural conditions, as seen in Fig. 6: (a) hunched posture, (b) swayed back, and (c) lowered right shoulder, which are compared to a baseline straight position (d). These postural conditions were chosen to reflect extreme examples of typical maladaptive positions observed during piano performance.

For the purpose of this pilot test, data about the positions of the head, shoulder center, right shoulder, and spine were chosen for comparison, since researchers are interested to know whether or not skeletal alignment of the head and torso can be impacted by somatic training. Given that the position of these particular points remained quite stable during testing, the average coordinate positions of the anatomical points of interest were calculated from the coordinate points measured by the Kinect, as reported in Table 1.

TABLE I. Average Position of Anatomical Points Tracked By Kinect During Piano Performance in Different Postural Conditions

Anat. point	**Baseline straight posture**			**Hunched condition**		
	x	y	z	x	y	z
Head	0.27	0.37	1.11	0.22	0.28	1.12
Shoulder Center	0.30	0.22	1.14	0.28	0.15	1.15
Right Shoulder	0.26	0.22	1.30	0.24	0.14	1.31
Spine	0.25	-0.08	1.18	0.29	-0.12	1.29
	Swayed back condition			**Lowered right shoulder**		
	x	y	z	x	y	z
Head	0.15	0.36	1.08	0.19	0.32	1.04
Shoulder Center	0.19	0.22	1.10	0.27	0.16	1.12
Right Shoulder	0.13	0.21	1.27	0.20	0.16	1.30
Spine	0.18	-0.08	1.14	0.26	-0.09	1.21

The Kinect sensor collects data at 30 frames per second with respect to the reference frame system depicted in Fig. 5. During the performance, since the pianist's hands would be moving back and forth from the Kinect perspective, it is to be expected that their *Z* coordinates would be constantly changing. An example for a player doing a contrary motion C major scale can be seen in Fig. 7.

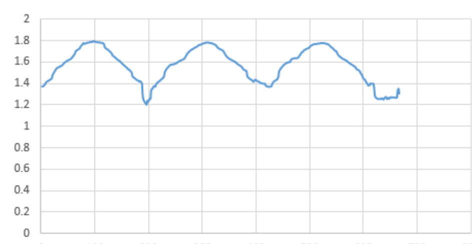


Fig. 7. Z coordinates of a pianist's hands during performance.

B. Gesture quantification results

Anatomical points from the baseline and exaggerated postural conditions were compared to see if the points changed positions in accordance with expectations established based on visual assessment of the postural conditions. It was found that the Kinect was able to reliably track the expected changes in most of the exaggerated conditions.

In a hunching position, the upper part of the torso collapses symmetrically, such that the head, shoulders, and midpoint between the shoulders should move downward in the *Y*-axis. Hunching also allows the head and shoulders to fall further forward toward the piano, indicating an expected decrease in *X*-axis values for these anatomical points. Since hunching results in a translational movement of the upper torso, the change in tracked position should be of a similar magnitude for all three points.

TABLE II. COMPARING X/Y COORDINATES OF HEAD AND SHOULDER POINTS IN BASELINE AND HUNCHING CONDITIONS

Anat. point	Expectations	Baseline Coord.(m)	Hunching Coord.(m)	Diff. (cm)	Expect. met?
Head	Y coordinate should be higher in baseline	Y =0.372	Y=0.277	9.5	Yes
	X coordinate should be lower in baseline (closer to piano)	X=0.268	X=0.222	4.6	Yes
Shoulder center	Y coordinate should be higher in baseline	Y=0.219	Y=0.146	7.3	Yes
	X should move slightly closer to the piano during hunching	X=0.300	X=0.280	2	Yes
Right Shoulder	Y coordinate should be higher in baseline	Y=0.215	Y=0.142	7.3	Yes
	X coordinate should be further from piano in baseline	X=0.261	X=0.242	1.9	Yes
Spine	Y coordinate may be slightly higher in baseline	Y=-0.079	Y=-0.122	4.3	Yes
	X coordinate may be slightly closer to piano in baseline	X=0.245	X=0.295	5	Yes

A sway back position involves translational movement of the upper torso toward the piano, such that the expected changes in position of the head and shoulders from baseline to swaying should be opposite to that of hunching. In this position, it is expected that the head, right shoulder, and shoulder center would move closer to the piano, while the spine marker should remain relatively constant compared to baseline. However this may not always occur because of the movement of the rest of the body. When swaying back, the keys may get out of range, so the player may choose to sit closer to the piano to be able to reach them.

TABLE III. COMPARING X/Y COORDINATES OF HEAD AND SHOULDER POINTS IN BASELINE AND SWAY BACK CONDITIONS

Anat. point	Expectations	Baseline Coord.(m)	Swayed Coord.(m)	Diff. (cm)	Expect. met?
Head	Y coordinate should be slightly lower in baseline	Y =0.372	Y=0.360	1.2	No
	X should be further from the piano in baseline	X=0.268	X=0.150	11.8	Yes
Shoulder center	Y coordinate should remain stable	Y=0.219	Y=0.219	0	Yes
	X should move closer to piano during sway (similar to head).	X=0.300	X=0.187	11.3	Yes
	Y should remain stable	Y=0.215	Y=0.205	1	Yes
Right Shoulder	Y should remain stable	Y=0.215	Y=0.205	1	Yes
	X coordinate should be further from piano in baseline	X=0.261	X=0.130	13.1	
Spine	Y coordinate should remain stable	Y=-0.079	Y=-0.084	0.5	Yes

With the right shoulder lowered, it would be expected that a prominent drop is seen in the *Y* value of the right shoulder, since it is being pushed down in the test condition. Because the bending motion is primarily occurring in the upper torso along the *Z* axis, very little change should be noted in the *X* values of the spine. It is also expected that the head would drop lower and to the right. From Table 4 it can be seen that the expected change in the *Z* coordinate of the head occurred in the opposite of the expected direction, since *Z* values should increase as they move closer to the Kinect. This observation may originate from the characteristically low accuracy of the sensor on depth measurements. The Kinect reliably tracked all other expected coordinate changes. The Kinect was able to capture that the head had dropped as the right shoulder pulled the body down. Also, it was able to tell that the right shoulder was closer to the piano when dropped to the right. We can observe a prominent drop in the right shoulder as expected.

TABLE IV. COMPARING X/Y COORDINATES OF HEAD AND SHOULDER POINTS IN BASELINE AND RIGHT-SHOULDER LOWERED CONDITIONS

Anat. point	Expectations	Baseline Coord.(m)	Low Sh. Coord.(m)	Diff. (cm)	Expect. met?
Head	Y coordinate should be slightly higher in baseline	Y =0.372	Y=0.321	5.1	Yes
	X should move forward slightly	X=0.268	X=0.193	7.5	Yes
	Z should move slightly up in this condition, since the head is pulled to the right and down when the right shoulder is dropped.	Z=1.111	Z=1.040	7	No
Shoulder centre	Y coordinate should be higher in baseline	Y=0.219	Y=0.155	6.4	Yes
	X should move slightly closer to the piano (similar to hunching)	X=0.300	X=0.274	2.6	Yes
Right Shoulder	Y coordinate should be higher in baseline	Y=0.215	Y=0.155	6	Yes
	X should move slightly closer to the piano	X=0.261	X=0.196	6.5	Yes
Spine	Y should remain stable	Y=-0.079	Y=-0.092	1.3	Yes
	X should remain stable	X=0.245	X=0.256	1.1	Yes

Overall, the results indicate that the Kinect can reliably track and quantify exaggerated postures of pianists. Examination of the data indicates that at times the Kinect momentarily loses track of anatomical points, even when their position is remaining relatively stable, or is changing slowly. In these cases, the Kinect momentarily reports data values much higher or lower than surrounding values. In future analysis, the application of a data filter would help remove any outlying data entries that could skew the results. It was also found that anatomical points further away from the Kinect, such as the left shoulder and left wrist, were frequently lost during tracking. In order to reliably track and quantify movement of all intended anatomical points and body segments, future tests could involve a procedure using two or more Kinects, perhaps both behind and beside the subject.

VI. Conclusion

Data analysis revealed that the Kinect sensor is able to track and quantify the characteristics of the upright posture of pianists reliably in exaggerated and relatively constant conditions. Since the torso and head remain in relatively fixed positions during some common playing tasks, such as the repetitions of technical patterns or reading music for the first time at sight, the results of this pilot test suggest that the Kinect would be a useful tool in tracking the characteristics of the baseline or neutral postures specific to different performers during such tasks. Further testing will be necessary to ascertain whether tracking would still occur reliably in a performing condition, during which the pianist's torso, shoulders, and head would likely pass through more variations in response to the technical and expressive demands of the music they are playing. Further testing will also have to be done to assess whether or not the Kinect is precise enough to track smaller differences in anatomical positioning, since it is hypothesized that changes to skeletal alignment as a result of somatic training are likely to be quite small, and less exaggerated than the postures used for these initial tests.

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