PIANO-RELATED MUSCULOSKELETAL DISORDERS: POSTURE AND PAIN

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A healthy posture protects the body-supporting functions and prevents injuries by maintaining balance. Literature in performing arts medicine suggests that posture is an important component to prevent piano-playing related injuries. However, no known research studies have quantified, characterized, and compared pianists' sitting postures. The purpose of this study was to explore the relationship between playing postures and perceived pain among pianists. This study applied innovative approach using qualitative and quantitative methods, combined with three-dimensional motion captured technology. To examine risk factors related pianists' postures, three-dimensional motion-capture cameras recorded approximate 40 pianists' postures in various situations; data recordings were combined with a statistical method to investigate pain-posture correlations. Results reveal that the degrees of head-neck or body tilt angles are the tendency of risk factors for piano-playing related pain. Results from this study may have multiple practical implications among which are: (1) a risk factor pain, injury index, or indicator (2) a performance habits profile and (3) practice guide to prevention of piano-playing related musculoskeletal disorders.

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ABBREVIATIONS

B	Bach
BT	Body-tilt
CT	Cervico-thoracic
G	Grieg
HN	Head-neck
KMO	Kaiser-Meyer-Olkin
LSP	Left shoulder protraction
M	Mozart
N	Neutral seated posture
NSP	Neutral seated posture
OB-q	Online baseline questionnaire
PA	Performance anxiety
PRMD	Playing-related musculoskeletal disorder
Pre-q	Pre-performance questionnaire
Post-q	Post-performance questionnaire
RSP	Right shoulder protraction
S.D.	Standard deviation
S.E.	Standard error
SR1	1^{st} sight-reading
SR2	2^{nd} sight-reading
TL	Thoracic-lumbar
VAS	Visual analogue scale

CHAPTER 1

INTRODUCTION

Pain is "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage."[1] Pain can promote destructive stress reactions such as neurological dysfunctions, fatigue and functional impairment, both mental and physical.[2] Musicians suffering from pain and playing-related musculoskeletal disorders (PRMDs) is a recognized problem.[3] Research in performing arts medicine suggests that musicians experience pain and upper extremity musculoskeletal problems from playing piano and that the PRMDs are caused by multiple interacting risk factors that include intrinsic and extrinsic factors.[4] Intrinsic factors include gender, age, physical size, strength, mental and physical condition, and personality.[5] Extrinsic factors consist of repertoire, genre, piano type, teachers, and the psychosocial environments.[6] Another set of interacting factors is interaction risk factors such as posture, technique, and music instruction.[7]

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[1] International Association for the Study of Pain (IASP), under "IASP Pain Terminology," http://www.iasp-pain.org/Content/NavigationMenu/GeneralResourceLinks/PainDefinitions/default.htm#Pain (accessed 12 March

[2] Richard Shampman and Jonathan Gavrin, "Suffering: the Contributions of Persistent Pain," *Lancet* 353 (1999): 2233.

[3] Alice G. Brandfonbrener, "Epidemiology and Risk Factors," in *Medical Problems of the Instrumentalist Musician,* ed. Raoul Tubiana and Peter C. Amadio (London: Martin Dunitz Ltd., 2000): 172-175; Pamela A. Hansen and Kristi Reed, "Common Musculoskeletal Problems in the Performing Artist," *Physical Medicine and Rehabilitation Clinics of North America* 17 (2006): 789-797; Chong Pak and Kris Chesky, "Prevalence of Hand, Finger, and Wrist Musculoskeletal Problems in Keyboard Instrumentalists," *Medical Problems of Performing Artists* 15 (2000): 20-21; Eri Yoshimura, Pamela M. Paul, Cyriel Aerts, Kris Chesky, "Risk Factors for Piano-related Pain among College Students," *Medical Problems of Performing Artists* 21, no.3 (2006): 122; Christine Zaza and Vernon T Fawarell, "Musicians' Playing-related Musculoskeletal Disorders: An Examination of Risk Factors," *American Journal of Industrial Medicine* 32 (1997): 292-300; Hunter J. Fry, "Prevalence of Overuse (Injury) Syndrome in Australian Music Schools," *British Journal of Industrial Medicine* 44 (1984): 35-40.

[4] Chong and Chesky, 20-21; Yoshimura et al., 122; Zaza and Fawarell, 300; Fry, 35–40.

[5] Zaza, 330; Fry, 35–40; Brandfonbrener, 171–194.

[6] Zaza, 330; Fry, 35–40; Brandfonbrener, 171–194.

[7] Sonia Ranelli et al., "Prevalence of Playing-related Musculsekeletal Symptoms and Disorders in Children Learning Instrumental Music," *Medical Problems of Performing Artists* 23 no.4 (2008): 179.

Prevalence rates of PRMD reported in research studies on pianists range from 38.1% to 91%, and pianists reported pain mainly around the neck, back, shoulder, and upper extremities.[8] Research also suggests that upper extremity musculoskeletal problems among pianists may be directly related to certain practice and performance habits, including sitting postures as a risk factor for pain and impairment.[9]

Definitions of a Posture and a Healthy Posture

The term "posture" is defined as the position of the body during rest or activity.[10] According to the Posture Committee of the American Academy of Orthopaedic Surgeons, a healthy posture protects the body-supporting functions and prevents injuries by maintaining balance.[11] This concept of a healthy normal posture inspired researchers to explore the relationship between postures and injuries.[12]

Common Poor Postures

The spine, head, neck, and shoulders are commonly negatively affected areas due to poor alignments.[13] Scientists have investigated the influence of specific spinal postures and shoulder positioning on muscle activity and pain over years.[14] Scientists measured the difference in kinematics and muscle activity in varied postures, including kyphosis, lordosis, and shoulder

[8] Brandfonbrener, 175-193; Hansen and Reed, 780-790; Pak and Chesky, 20-21.

[9] Brandfonbrener, 175-193.

[10] Lance T. Twomey and James R. Taylor,"Lumbar Posture, Movement, and Mechanics," in *Physical Therapy of the Low Back*, 3rd ed. Lance T. Twomey and James R. Taylor (Melbourne: Churchill Livingstone, 2000), 59.

[11] Rene Cailliet, *Low Back Pain Syndrome*, 3rd ed. (Philadelphia: F. A. Davis Co,1981): 23.

[12] Christopher M. Norris*, Back Stability: Integrating Science and Therapy*, 2nd ed. (Champaign, IL: Human Kinetics, 2008): 3-12.

[13] Jan Dommerholt, "Posture" in *Medical Problems of the Instrumentalist Musician,* ed. Raoul Tubian and Peter C. Amadio (London: Martin Dunitz Ltd., 2000): 403-404; Henry O. Kendall et al., *Posture and Pain*, (New York: R E Kreiger Publishing Co., 1952): 15-48.

[14] Peter B. O'Sullivan, et al., "Effect of Different Upright Sitting Postures on Spinal-pelvic Curvature and Trunk Muscle Activation in a Pain-free Population," in *Spine* 31 no.19 (2006): 3-5; Michael A. Adams and William C. Hutton, "The Effect of Posture on the Lumbar Spine," in *Journal of Bone and Joint Surgery* 67B (1985): 627.

protraction.[15] A normal lumbar lorodsis maintains the natural curve in the cervical spine.[16] A kyphosis, so called "roundback" or "hunchback" is a reversal of a normal lumbar lordosis that increases posterior curve in the cervical spine.[17] A hypolordosis, so-called swayback, is an increased anterior curve of the spine, which is usually associated with an anterior pelvic tilt.[18] A shoulder protraction causes the shoulder blades to shift anteriorly and to change in scapular position.[19] The authors concluded that any kyphosis, hypolordosis, and shoulder protraction creates an undesirable stress in the cervical spine and scapula, while an upright sitting posture that maintains normal lordotic and shoulder positions reduces muscle activities in the cervico-thoracic area and promotes spinal health.[20]

Regarding the head and neck region, previous studies suggest that small changes in head position or head/neck angle can affect the load on supporting structures and muscle activity, and can increase pain.[21] One of the most common abnormal postures is the forward head posture, which is often described as a turtleneck.[22] Several studies have demonstrated that prolonged neck and shoulder pain may be associated with the degree of forward head postures and creates impact on patterns of muscle activity when sitting.[23]

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[15] O'Sullivan et al., 3-5; Joao P. Caneiro, et al, "The Influence of Different Sitting Postures on Head/Neck Posture and Muscle Activity," in *Manual Therapy* 15 (2010): 55-60; Makikutlo Kebaetse et al., "Thoracic Position Effect on Shoulder Range of Motion, Strength, and Three-dimensional Scapular Kinematics," in *Archives of Physical Medicine and Rehabilitation* 80 no.8 (1999): 945-950.

[16] Kendall et al., 15.

[17] Kendall et al., 15.

[18] Noris, 74.

[19] Kebaetse et al., 945-950.

[20] O'Sullivan et al., 3-5 ; Adams and Hutton, 626-627; Kebaetse et al., 945-950.

[21] Karin Harms-Ringdahl et al., "Load Moments and Myoelectric Activity When the Cervical Spine is Held in Full Flexion and Extension," in *Ergonomics* 29 (1986): 1541-1952; Grace P.Y. Szetoet al., "A Comparison of Symptomatic and Asymptomatic Office Workers Performing Monotonous Keyboard Work—2: Neck and Shoulder Muscle Recruitment Patterns," in *Manual Therapy* 10 no.4 (2005): 284-290.

[22] Jan Dommerholt, 403-404; Kendall et al.,18-21.

[23] Geertje Ariens et al. "Are Neck Flexion, Neck Rotation, and Sitting at Work Risk factors for Neck Pain? Results of a Prospective Cohort Study," *Occupational and Environmental Medicine* 58, no.3 (2001): 203-207; Szeto et al., "A Field Comparison of Neck and Shoulder Postures in Symptomatic and Asymptomatic Office Workers," in *Applied Ergonomics* 33 (2002): 78-83.

Ergonomic Literature on Computer Keyboard Users

The ergonomic literature suggests that the upper extremities' posture is one of the primary etiological factors associated with musculoskeletal disorders among people who use computer keyboards.[24] Static posture associated with computer work has been identified as a major occupational risk factor, particularly in the regions of the neck, shoulders, and the upper limbs.[25]

There are similarities between computer keyboard users and pianists regarding the tasks that require the forward tilting of the upper body. Unfortunately, as opposed to the ergonomic field, there are no known research studies that have quantified, analyzed, or characterized advanced pianists' sitting postures and related outcomes including pain. Due to the lack of research on this topic, critical questions regarding the relationship between pianists' posture and pain remain unanswered.

Hypothesis

This study hypothesizes that practice and performance habits such as postures are correlated to piano playing-related injuries.

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[24] Harms-Ringdahl et al.,1541-1952.
[25] Harms-Ringdahl et al.,1541-1952.

Purpose of the Study

Rationale: Research in performing arts medicine suggests that playing-related injuries are a recognized problem amongst piano performers and these problems among pianists may be directly related to certain practice and performance habits, including sitting postures as a risk factor for pain and impairment. Yet there are no known research studies that have characterized and compared advanced pianists' sitting postures and explored correlations between pianists' postures and related outcomes including pain.

The research objective of this study is to explore the relationship between playing postures and pain among pianists. Specifically, this study quantified pianists' postures and piano-playing related factors. The specific aims of this study were to 1) assess demographics and piano-related experiences, 2) measure anthropometric indices, 3) characterize and compare head, neck, and upper body postures while in a static seated position and during dynamic performance situations, and 4) examine correlations among pianists' postures and intrinsic, extrinsic, and interaction risk factors.

CHAPTER 2

METHODS

Subjects

Following approval of this study by the UNT Institutional Review Board (IRB), thirty-nine active pianists with professional piano training were recruited from the UNT piano department and the local community. Inclusion criteria were the ability to learn and perform three assigned pieces by memory within a month.

Procedures

Thirty-nine pianists were invited to participate through personal contacts. Each pianist signed an IRB approved informed consent form prior to participation in the study. Three musical selections were provided to pianists with specific performance instructions by including fingerings, approximate tempi, dynamics, and pedal markings to be able to play by memory as in performance. Pianists were also provided with the web link to the online baseline questionnaire (OB-q). Pianists were scheduled for the lab visit according to their availabilities.

An online baseline questionnaire was administered prior to the scheduled day of testing. On the scheduled trial day, pianists were instructed to put on a tight, modified shirt for the placement of reflective markers in a private room before the investigator took bilateral anthropometric and functional capacity measurements of the upper extremities. A total of eight reflective markers were attached to the occiput on the head, right and left postero-lateral acromions, and to the skin on vertebral spinous processes of C7, T4, T7, L3, and S2 tubercle of the sacrum (Figure 1).

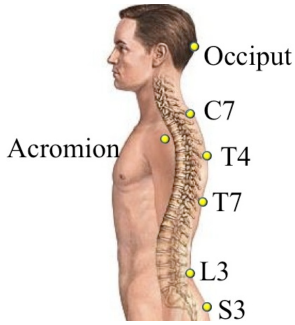

Figure 1: Selected bony landmarks for the placement of reflective markers [26]

Two additional markers were located by the piano to establish a horizontal axis. To ensure accurate and consistent placement of reflective markers, subjects were requested to recline face down on a massage bed that includes a face cradle. Pianists then moved to the piano, and were asked to adjust the piano bench height to their preferred levels and then bench height was recorded. While at the piano, pianists answered the pre-performance questionnaire (Pre-q) and warmed up at the piano for about two minutes. Before playing the memorized pieces, motional capture technologies were turned on. Three three-dimensional motion captured cameras by Qualisys motion captured system were used for tracking reflective markers on the subject's upper body segments, and two digital video camera systems provided pianists' side and back images.[27] First, pianists' head, neck, and back of neutral seated posture were recorded for two seconds while pianists remained steady. All postural measurements of motions were initiated and terminated using an external trigger device, which was attached to the camera system. Before each piece, approximate performance tempi of the musical selections were presented to pianists via a metronome before each piece. Pianists played each piece by memory while dynamic postures were assessed using the motion capture technologies. When the pianist was finished, a new music was presented to pianists with the instructions not to touch the keyboard

[26] Spinal Clinical Examination, under "Clinical Examination of the Spine," http://www.ivline.info/2010/10/clinical-examination-of-spine.html (accessed 17 May 2012).

[27] Qualisys motion capture track manager by Qualisys Motion Capture Systems, Inc. (Gotehnburg, Sweden).

until ready to perform. Pianists were provided with 30 seconds for reviewing the new piece. Immediately following the first sight-reading task, pianists followed the exact same procedure as the first sight-reading task for the second sight-reading task. After sight-reading tasks, pianists answered a post-performance questionnaire (Post-q). Compensation was provided following completion of the protocol. A flow chart of a whole procedure shows the entire procedure of this study (Figure 2). The details of online baseline, pre-, and post-questionnaires used are described in the Assessment section.

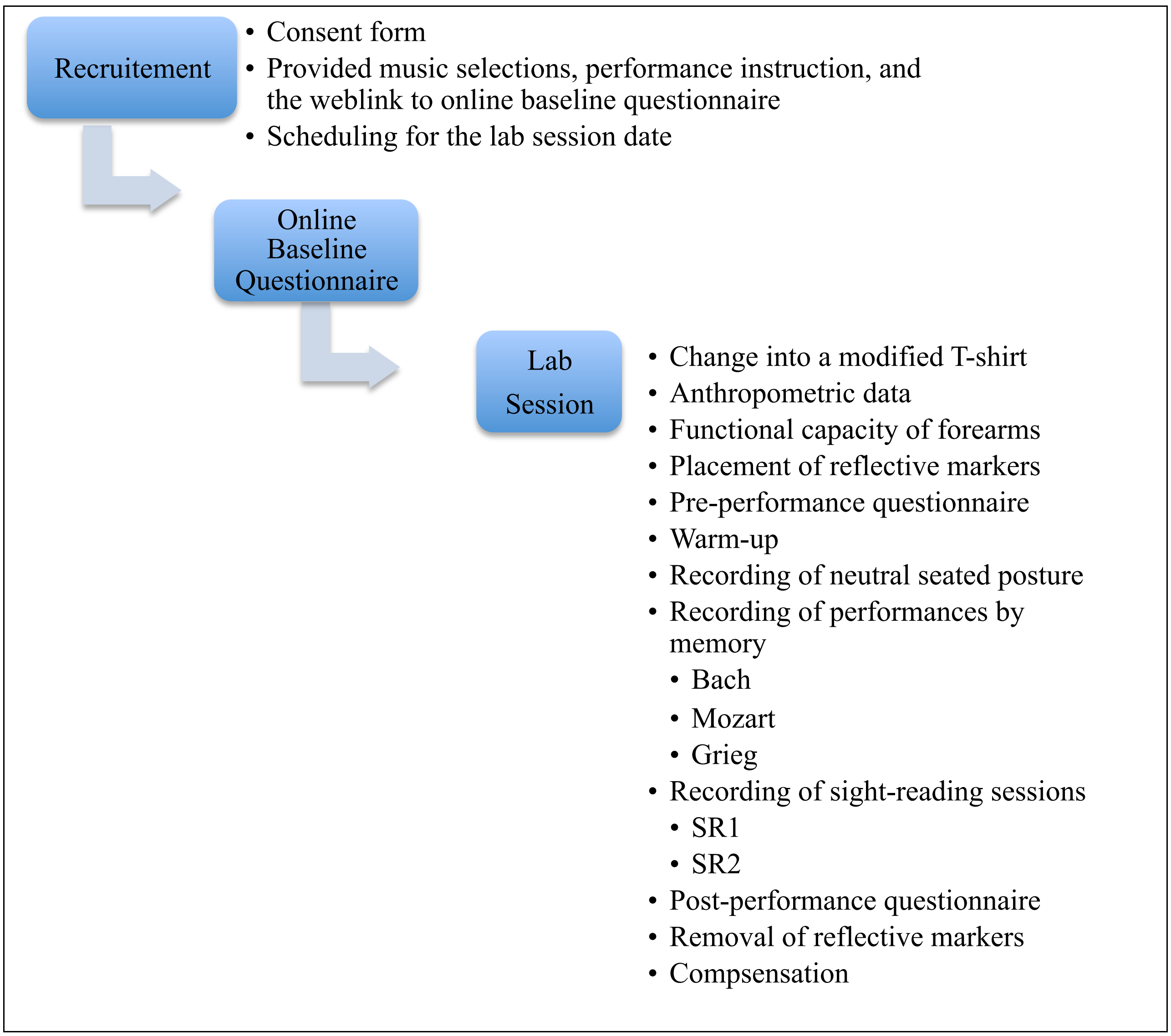

Figure 2: Flow chart of the procedure

Musical Selections

Assigned musical selections for the experiment for a pianist to perform by memory were the first eleven measures of Prelude No.1 in C major from *Well-Tempered Clavier Book I*, BWV 846 by Johann Sebastian Bach, of the first thirteen measures of the first movement of Piano Sonata no.16 in C major K.545 by Wolfgang Amadeus Mozart, and the first three measure of the first movement of the Piano Concerto in A minor Op.16 by Edward Grieg. Throughout the dissertation, these musical selections or performances on these compositions are stated by the composer's name. For the sight-reading, "Dream" by Da Jeong Choi, a piece which had not yet premiered by the trial dates, was used after receiving authorization from the composer. Two varied sections from "Dream" were used for the first and second sight-reading tasks. The first sight-reading section is notated as SR1 and the second session as SR2 for purposes of discussion. These pieces were chosen by the author based on the variability of difficulty in technique, musical styles, and performance techniques. The technical difficulty levels rated by pianists are discussed in Results section. Bach is characterized by constant, repetitive arpeggiated passages by both hands. Mozart consists of melodic lines on a right hand and alberti bass left hand followed by running scales of a right hand. Grieg features descending cords and octaves in both hands with fortissimo. SR1 from "Dream" is characterized with simple rhythms with contrary motions in both hands including long rests. SR2 features upbeat, complicated rhythms, running passages, and repetition of sixteenth-note chords in right hands with dissonant harmonies. The approximate tempi were decided based on the musical styles for each piece based on piano literature. Each tempi was 70 for a half-note for Bach, 120 for a quarter-note for Mozart, and 76 for a quarter-note for Grieg.

Assessments

Online Baseline Questionnaire

The online baseline questionnaire consisted of two sections designed to assess 1) demographics and 2) piano performance-related experiences: i) pain, ii) piano educational background, iii) practice habits, iv) piano-related activity in hours that pianists spend at a piano per week, v) stress, performance anxiety (PA), and confidence level, and vi) postural and body awareness. Demographic and musical background questions assessed variables such as gender, ethnicity, age, marital status, starting age at the piano, number of years of private lessons, and number of piano-playing-method workshops attended. Questions about piano performance-related experiences of pain questions were designed to assess pain associated with piano playing, influence of pain on performance, perceptions of pain intensity, and frequency of pain during piano playing over the previous week as well as on the trial day. Practice habits included questions related to warm-up and breaks taken during practice. These questions were computed and recorded by digital visual analogue scales (VAS) that required subjects to scroll the cursor to reflect their responses. The score was recorded either from 0 to 10 or 0 to 100 scales. VAS was used for this study for its valid and reliable methodology for measuring pain.[28]

Anthropometric Measurement

A series of twenty anthropometric indices were assessed using a flexible plastic tape measure and body calipers according to standardized protocols and specific anatomical

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[28] Joel Katz and Ronald Melzack, "Measurement of Pain," *Surgical Clinics of North America* 79 (1999): 233-251; Anna Carlsson, "Assessment of Chronic Pain I. Aspects of the Reliability and Validity of the Visual Analogue Scale," *Pain* 16 (1983): 88-101.

landmarks as described in the previous piano studies.[29] Anthropometric indices included bilateral measures of upper and lower arm lengths, hand spans and lengths, and shoulder width and heights. Non-bilateral measures included neck length and circumference, head circumference, and sitting height. Data on the difference of right and left shoulders' height was calculated as [(right shoulder height (mm)) – (left shoulder height (mm))] and the subtracted number was recorded in absolute value.

Functional Capacities of Forearms

Functional capacities of the upper extremities were assessed bilaterally and included forearm ranges of motion and rotation speeds. Testing for both supination and pronation movements were examined according to the basic elements of performance theory and the XII System, which was also applied in the previous study.[30]

Pre- and Post-Performance Questionnaires

Pre- and post-performance questionnaires asked the pianist's current physical and mental conditions before and after subjects perform. Questions in this section included the degrees of perception of pain, tiredness, tension, coldness, nervousness, and eyesight. Pre- and post-performance questionnaires consisted of the exact same questions except for the questions about perception of difficulties on two assigned sight-reading pieces in the post-performance questionnaire. These questions were measured by 100 mm visual analogue scales (VAS) that

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[29] Yoshimura et al., 119-121; Katrin L. Meidel, "Epidemiologogical Evaluation of Pain Among String Instrumentalists," D.M.A. dissertation, University of North Texas (2011): 12-14.

[30] Human Performance Measurement, Inc. (Arlington, TX); Yoshimura et al., 121.

required pianists to mark single vertical lines to reflect their responses. A body drawing was used to indicate locations and types of pain.

Postural Measurement

Skin surface three-dimensional tracking by using reflective markers has been validated to measure the change in spinal curve.[31] Specific bony landmarks were chosen for the postural measurement based on the studies in the literature and the guidance by a chiropractic physician who was also a chair at the chiropractic department at Parker University. C7, T4, and acromions were chosen based on a previous study to measure a head-neck posture.[32] The latter studies showed that T4 and T7 can be reliably and accurately measured.[33] Acromions, L3, and S2 were also applied in the postural measurement for lumbar angles.[34]

To characterize the upper body, head, neck, and back postures while in a static neutral seated position and during dynamic performance situations, the defined angles of an individual's upper body segments were computed with Qualysis motion analysis software and representative sequence of numbers were exported to Excel software. Two vertical lines among any three bony landmarks or a horizontal Z-axis generated a total of six angles. The defined angles of the subjects' upper body segments included head-neck (HN), cervico-thoracic (CT), thoracic-lumbar (TL), body-tilt (BT), right shoulder protraction (RSP), and left shoulder protraction (LSP) (Figure 3). Body-tilt angle was created with the mean of the five angles created by two vectors

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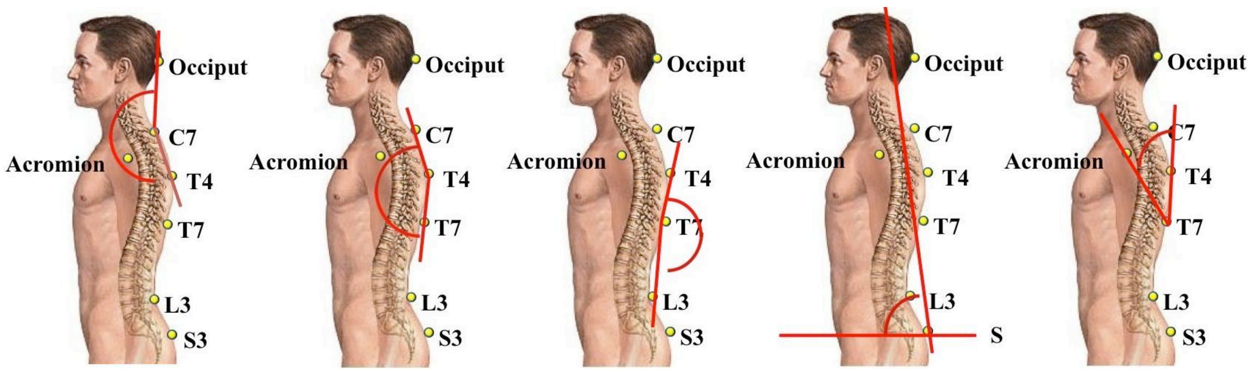
[31] Serge Gracovetsky, Kary M, Stephen Levy, Ben R. Said, Pitchen I, and Adam J. Helie . "Analysis of Spinal and Muscular Activity During Flexion/extension and Free Lifts," *Spine* 15 no.12 (1990): 1333–1339; Morl Falk,and Reinhard Blickhan, "Three-Dimensional Relation of Skin Markers to Lumbar Vertebrae of Healthy Subjects in Different Postures Measured by Open MRI," *European Spine Journal* 15 no.6 (2006):742–751.

[32] Stephen Edmondston et al., "Postural neck pain: an Investigation of Habitual Sitting Posture, Perception of 'Good' Posture and Cervicothoracic Kinesthesia," *Manual Therapy* 12 (2007): 363 – 371.

[33] Markus Ernst, et al., "Determination of Thoracic and Lumbar Spinal Processes by Their Percentage Position Between C7 and the PSIS level," *BioMed Central Research Notes* 6 (2013): 58.

[34] Andrew P. Claus, et al., "Is 'Ideal' Sitting Posture Real?: Measurement of Spinal Curves in Four Sitting Postures," *Manual Therapy* 14 (2009): 405.

between Z-axis and a vector from S to the five bony landmarks: an occiput, C7, T4, T7, and L3.[35]



Head-neck Cervico-thoracic Thoracic-lumbar Body-tilt Shoulder-protraction

Figure 3: Definitions of head-neck, cervico-thoracic, thoracic-lumbar, body-tilt, and shoulder protraction angles [36]

Means, standard deviations, and range of the defined angles were recorded for each pianist. With regard to HN angles, the smaller the angles, the more the pianists are facing downward; the wider the angles, the more the pianists' heads are in an upright position. Considering TL, the smaller the angles, the more the pianists have posterior curve in their lower backs. Regarding CT angles, the smaller the angles, the more the pianists are having more curves in the upper back. The degree of BT measures how much a pianist's whole body tilts. The smaller the BT angles, the more pianists' whole bodies tilt forward.

The difference between the NSP mean for each angle and the mean of each corresponding angle during Bach, Mozart, Grieg, SR1, and SR2 were also recorded. This angle difference was calculated as [(mean of each angle during various performances) – (mean of

[35] Holizontal line = Z axis, Body-tilt angle = the angles: [(occiput – S3 – Z axis) + (C7 – S3 – Z axis) + (T4 – S3 – Z axis) + (T7 – S3 – Z axis) + (L3 – S3 – Z axis)] / 5.

[36] Spinal Clinical Examination, (accessed 17 May 2012).

corresponded angle in NSP)]. For example, the HN angle difference during Bach was calculated as [(mean of HN angle in Bach) – (mean of HN angle in NSP)] and will be notated as HN of (B – N) in tables. Throughout this dissertation, the mean angle was used to characterize all measured postures (HN, CT, TL, BT, RSP, and LSP).

Quality of Measurement

Confirmatory Factor Analysis was conducted to test quality and validity of all the questionnaires and to examine whether the qualitative data fit a hypothesized measurement model.[37] All the variables from the questionnaires were subjected to Confirmatory Factor Analysis by maximum likelihood method. Variables with coefficients of absolute value above 0.32 were extracted to create a factor. A factor, which is a group of highly inter-correlated characteristics of items, resulted from Confirmatory Factor Analysis can be applied to statistical tests of significance.[38] Factors with Kaiser-Meyer-Oklin values that exceeded the recommended value of 0.6 and with Bartlett's Test of Sphericity that reached statistical significance ($p < 0.05$) were determined to be suitable for the factor analysis by supporting the factorability of the correlation matrix.[39]

Data Analysis

All statistical analysis was analyzed with Statistical Package for the Social Sciences (SPSS) version 21. The measures used to describe the data set were measures of central tendency and measures of variability or dispersion. Mean and medium were calculated as

[37] Karl G. Jöreskog, "A General Approach to Confirmatory Maximum Likelihood Factor Analysis," *Psychometrika* 34 no.2 (1969): 183-202.

[38] Rummel J. Rudolf, *Applied Factor Analysis* (Illinois: Northwestern University Press, 1970): 522-566.

[39] Julie Pallant, *SPSS Survival Manual: a Step by Step Guide to Data Analysis Using SPSS for Windows* (United Kingodm: Open University Press, 2007), 179-199.

measures of central tendency; to observe measures of variability the standard deviation and the range (minimum and maximum) were calculated.

Descriptive Analysis

The data from the questionnaires, anthropometric measurement, functional capacity measurement, and postural measurement were analyzed using descriptive statistics (mean, standard deviation, maximum, and minimum) and frequency counts with SPSS. For categorical variables, such as gender and ethnicity, frequency and percentage were used for analysis. To characterize and compare pianists' postures and data from VAS from the questionnaires, data standard parametric statistical indicators—such as mean, standard deviation, and range—were calculated.

Comparing Neutral Seated Posture to Performance Postures

Paired-samples *t*-test was applied to compare the means of an angle in NSP and angles during performances to examine whether there is any difference between the two variables.

Bivariate Correlations

Bivariate analysis, using Pearson's correlation coefficient, was used to determine non-linearity relationships. Correlations between two variables related to intrinsic, extrinsic, and interaction risk factors were explored and compared by bivariate correlations. Specifically, postures versus pain, posture-related variables versus pain, non-posture-related variables versus pain, posture versus posture-related variables, and non-posture-related variables versus postures were calculated with Pearson's correlation coefficients (r).

Linear Regression

Linear regression analysis was applied for prediction or determining variable importance or examining how variables are related in the context of models. This regression analysis was conducted for each dependent variable using a pain factor as an independent variable. The regressions models consisted of postures related to pain and correlated variables to pain: sight-reading and hands awareness while playing, general stress and nervousness before the trial performance. The F value was used to determine statistical significance of the regression equation. The adjusted R^2 and beta value were computed and used to represent the amount of variance accounted for by the predictors and the importance or weights of the variables.

CHAPTER 3

RESULTS

Quality of Measurement

Based on confirmatory factor analysis described in the Methods section, the total of four factors reached the criteria to be identified as factors (Table 1).

Table 1: Test values of Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Barlett's test of sphericity

Factors	KMO Measure of Sampling Adequacy	Barlett's Test of Sphericity (Sig.)
Pain	0.615	0.000
Postural and body awareness	0.714	0.000
Physical and mental conditions (Pre-q)	0.647	0.000
Physical and mental conditions (Post-q)	0.737	0.000

* Pre-q = pre-performance questionnaire, Post-q = post-performance questionnaire

Extracted factors included 1) pain from all the questionnaires 2) postural and body awareness, 3) mental and physical conditions from pre-performance questionnaire, and 4) mental and physical conditions from post-performance questionnaire. Number of pain problems from pre- and post-performance questionnaires were eliminated from a pain factor. Fingers and hands awareness was eliminated from a body and postural awareness factor. The question about eyesight and feeling cold from pre- and post-performance questionnaires were also excluded (Table 2).

Table 2: Extracted factors from confirmatory factor analysis

Pain factors	Factor
	1
How often do you experience pain WHEN playing piano?	0.859
How often do you experience pain AFTER playing piano?	0.785
How often does pain stop you from playing piano?	0.741
Level of the pain from playing piano (%)	0.827
Do you feel pain now? (-q)	0.361
Pain Intensity (Pre-q)	0.655
Do you feel pain now? (Post-q)	0.549
Pain Intensity (Post-q)	0.706

Postural and body awareness	Factor		
	1	2	3
Posture awareness	0.441		0.423
Muscle tension awareness	0.804	0.594	
Muscle relaxation awareness	0.504		0.389
Body movements awareness	0.392		0.475
Fingers/Hands awareness			
Do you think you play piano with a good posture?	0.802	-.0596	

Physical and mental conditions (Pre-q)	Factor	
	1	2
Are you physically tired now? (Pre-q)	0.794	-0.152
Are you mentally tired now? (Pre-q)	0.663	-0.409
Do you feel nervous now? (Pre-q)	0.469	0.400
Do you feel any tension? (Pre-q)	0.619	0.509
Do you feel cold now? (Pre-q)	0.356	-0.312

Physical and mental conditions (Pre-q)	Factor
	1
Are you physically tired now? (Post-q)	0.601
Are you mentally tired now? (Post-q))	0.695
Do you feel nervous now? (Post-q)	0.756
Do you feel any tension? (Post-q)	0.811
Do you feel cold now? (Post-q)	

Descriptive Analysis: Online Baseline Questionnaire

Demographics

The study participants ranged in age from 19 to 59 years with the average of 28.4 year old, including 13 males (33.3 %) and 26 females (66.7 %). Thirty-one subjects (79.5 %) reported Asian and eight subjects (20.5%) reported Caucasian ethnicities. Thirty-one subjects are single and eight subjects are married. On average, subjects reported 4.72 exercise hours per week, 7.13 sleep hours, and 2.77 meal times per day (Table 3).

Table 3: Demographics

	Min	Max	Mean	S.D.
Age	19	59	28.41	6.361
Children Number	1	3	1.21	0.570
Exercise Hour	1	21	4.72	4.316
Sleep Hour	5	12	7.13	1.174
Meals Times	2	3	2.77	0.427

Piano-Related Experiences: Pain

Table 4 shows the responses to the pain questions from the online baseline questionnaire. All pianists reported piano-related pain. The reported pain experiences for WHEN, AFTER, and stopping playing the piano are showed in Table 4. The reported frequency of occurrences ranged from 0 to over 9.0 on a VAS scale ranging from never (0) to always (10).

Table 4: Pain questions from online baseline questionnaire

	Min	Max	Mean	S.D.
How often do you experience pain WHEN playing piano?*	0	9.2	3.054	2.418
How often do you experience pain AFTER playing piano?*	0	9.1	3.497	2.425
How often does pain stop you from playing piano?*	0	9.7	2.649	2.384
Level of the pain from playing piano (%)**	0	60.0	25.15	17.739

* VAS = 0 – 10 (Never – Always), ** VAS = 0 - 100

Piano-Related Experiences: Piano Educational Background

Thirty-six pianists (92.3%) majored in classical performance, two (5.1 %) in piano accompanying, and one (2.6 %) in music education. Five (12.8 %) reported pursuing a bachelor degree, 15 (38.5%) a master degree, and 19 (48.7 %) a doctoral degree (Table 5). As show in Table 6, the average age pianists reported starting piano was 6.5 years, ranging from two to 19 years. Pianists reported an average of 16.8 years of piano lessons, 11.4 performances per year, in total ranging from one to 25 performances. Eleven subjects have attended an Alexander technique piano workshop at least once and two subjects attended a Taubman piano method workshop at least once.

Table 5: Majors and degrees

	Frequency	Valid Percent
Classical performance	36	92.3
Piano accompanying	2	5.1
Music education	1	2.6
Bachelor	5	12.8
Master	15	38.5
Doctor	19	48.7

Piano-Related Experiences: Piano-Related Activities Hour per Week

As shown in Table 6, subjects reported the number of hours per week for various piano-related activities. The highest average number of hours per week was reported for practicing (17.87 hours), followed by rehearsals.

Piano-Related Experiences: Practice Habits

On a VAS scales ranging from 0 (never) to 10 (always), subjects reported 6.7 for how often they take breaks during practice. The duration of the breaks was reported as less than 4 minutes. For the day of the lab session, subjects reported playing the piano for 4.34 hours (Table 6).

Table 6: Piano educational background,
piano-related activities hour per week, and practice habits

	Min	Max	Mean	S.D.
Starting age	2	19	6.05	3.879
Total years of piano lessons	5	26	16.77	4.738
Total numbers of piano method workshops participated	0	2	0.33	0.530
Total number of medical treatments to PRMDs	0	4	1.28	1.191
Number of performances	1	25	11.41	6.738
Gig hour	1	41	5.56	8.152
Lesson hour	1	4	2.08	0.532
Practice hour	3	37	17.87	8.730
Rehearsal hour (chamber, accompanying)	1	21	6.26	4.854
Sight-reading hour	1	11	3.67	2.506
Teaching hour	1	31	5.62	6.628
Do you warm up before you spend time at piano?*	0	10.0	3.303	3.116
Time spent for warm-up (minutes)	1	10	2.87	1.852
Do you take break during practice?*	2.5	10.0	6.733	2.480
Duration of break (minutes)	2	18	3.72	2.743
How often do you take breaks during practice? (every/ minutes)	3	15	10.08	2.718
Do you stop daily practice because you are physically tired?*	0	9.8	3.877	2.564
Do you stop daily practice because you are mentally tired?*	0.1	10.0	5.362	2.421
Hours of piano playing on the trial day	1	16	4.34	2.869

* VAS = 0 – 10

Piano-Related Experiences: Trauma History and Treatments to PRMDs

The average number of medical treatments for PRMDs was 1.3 and 30 % (N = 28) of the pianists had applied some kind of treatments to PRMDs within twelve months. Seventeen pianists (43 %) experienced physical trauma or an accident that affected the ability to play (Table 7).

Table 7: Trauma history and treatments to PRMDs

Trauma history and Treatments to PRMDs	Frequency	Valid Percent
Medical treatment experience	11	22.0
Acupuncture	10	20.0
Chiropractic treatment	8	16.0
Heat	7	14.0
Massage	15	30.0
Non-prescribed medical treatment	7	14.0
Prescribed medical treatment	3	6.0
Physical trauma or accident that affects the ability to play piano	17	43.6

Piano-Related Experiences: Stress, Performance Anxiety, and Confidence Level

Stress, performance anxiety (PA) and confidence level were also examined (Table 8). 100% of participants reported experiencing general stress and stress as a pianist. Thirty-eight (97.40%) pianists reported PA experience. The average level of general stress in daily life was 49.28%, stress as pianist was 55.44%, and confidence as a pianist was 55.80%. Occurrence of PA was an average of 6.2 times and level of PA was 53%. Pianists indicated that PA affects them an average of – 4.7% (negative affect).

Table 8: Stress, performance anxiety, and confidence as pianist

(%)	Min	Max	Mean	S.D.
General stress	5	100	49.28	23.678
Stress as pianist	7	100	55.44	27.737
Occurrence of PA*	0	10.0	6.221	3.300
Level of PA**	0	100	53.05	29.631
How much affected by PA	-50.0	39.0	-4.78	19.904
Confidence as pianist	4.2	85.0	55.78	21.763

* VAS = 0 – 10, ** VAS = (- 50) – (+50)

Piano-Related Experiences: Postural and Body Awareness

Overall, subjects reported high and varied levels of frequency of awareness for posture, tension, etc. Subjects reported being aware of fingers and hands more than posture, muscle tension, muscle relaxation, and body movements. On VAS scale ranging from "not at all" (0) to "best possible" (100), the average score of 59.79 was reported for thinking they play with good posture (Table 9).

Table 9: Postural and body awareness

Awareness (%)	Min	Max	Mean	S.D.
Posture	0	91	47.13	20.648
Muscle tension	0	96	48.79	25.751
Muscle relaxation	0	96	57.59	25.853
Body movements	0	96	49.03	24.954
Fingers and hands	35	100	77.82	16.627
"Do you think you play piano with a good posture?" (%)	0	91	59.79	17.930

* VAS = 0-100

Descriptive Analysis: Pre- and Post-Performance Questionnaires

Table 10 represents responses to questions regarding pain and physical and mental conditions from pre- and post-performance questionnaires. The average of pain experience slightly decreased from post- to pre-performance as opposed to the average of pain intensity that increased from pre- to post-performance. However, the results from paired-samples *t*-test shows that both pain experience and pain intensity's scores did not differ from pre to post-performance. All the scores rated for physical and mental conditions decreased after the trial performances. Only physical tiredness showed a significant difference in scores on the pre- and post-performance questionnaires.

Table 10: Pain and physical and mental conditions from pre- and post- performance questionnaires

Questions	Pre-q Mean (SD, Range)	Post-q Mean (SD, Range)	*t*	Sig. (2-tailed)
Do you feel pain now?	0.979 (1.991, 0 – 9.8)	0.961 (1.967, 0 – 9.9)	0.096	0.924
Pain Intensity	0.421 (1.023. 0 – 4.0)	0.539 (1.155, 0 – 4.0)	-1.184	0.245
Are you physically tired now?	2.87 (2.590), 0 – 9.0)	2.150 (2.232, 0 – 7.3)	2.098	0.006
Are you mentally tired now?	3.426 (2.671, 0 – 10.0)	2.816 (2.671, 0 – 10.0)	2.018	0.051
Do you feel nervous now?	2.053 (1.944, 0 – 6.3)	1.274 (1.784, 0 – 6.1)	2.322	0.026
Do you feel any tension?	1.626 (1.574, 0 – 5.8)	1.253 (1.448, 0 – 5.3)	1.388	0.173
Do you feel cold now?	1.987 (2.758, 0 – 9.3)	1.353 (2.249, 0 – 8.1)	2.351	0.024
Can you see well now?	9.087 (1.215, 5.5 – 10.0)	9.184 (1.075, 6.0 – 10.0)	-.0593	0.557

* VAS = 0 - 10

Technical Difficulty Level for Musical Selections

The technical difficulty levels for musical selections are shown in Table 11. Technical difficulty increased in order from Bach, Mozart, Grieg, SR1, to SR2.

Table11: Technical difficulty level for the assigned tasks

Musical selections	Min	Max	Mean	S.D.
Bach	0	6.3	0.979	1.513
Mozart	0	6.5	1.439	1.748
Grieg	0	10.0	2.008	2.132
SR1	0	9.1	2.382	2.227
SR2	0	9.2	4.805	2.636

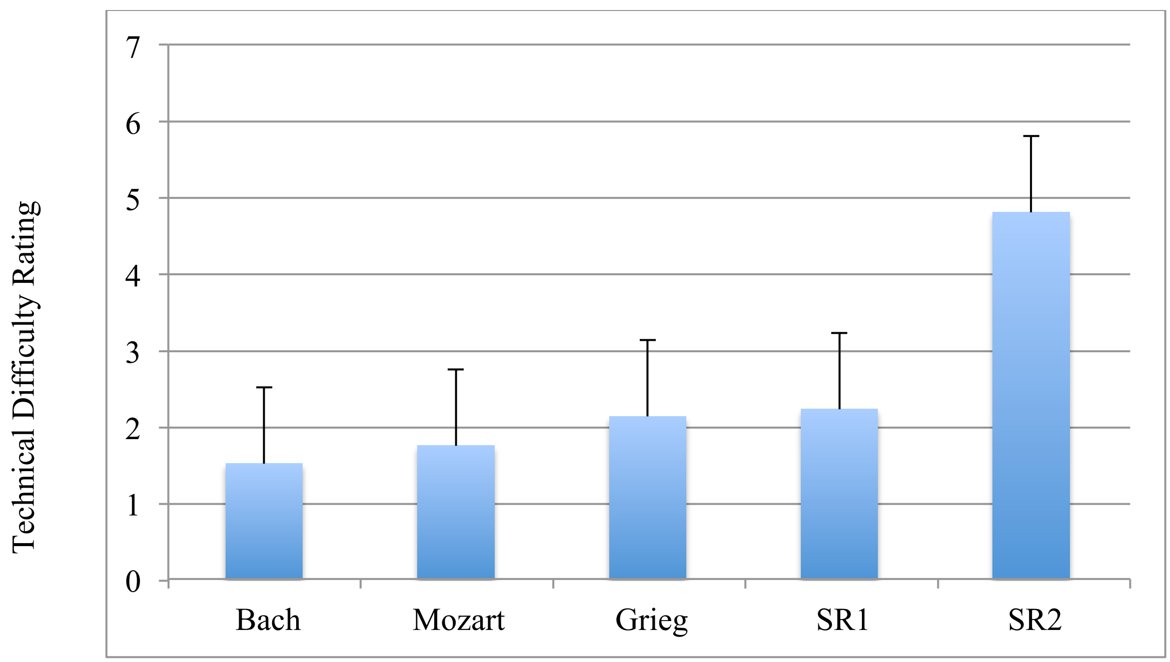


Figure 4: Technical difficulty level for the assigned sight-reading tasks

Descriptive Analysis: Anthropometric Data

Descriptive analysis of anthropometric measurements and functional capacities of forearms are shown in Table 12. On average, the range of motions and rotation speeds by right hands are greater than left hands; supinations are greater than pronations.

Table 12: Anthropometric indices and functional capacities of forearms

Anthropometric indices	Min	Max	Mean	S.D.
Height (cm)	149.8	189.8	167.874	8.593
Weight (kg)	38.4	100.6	63.390	13.732
BMI (%)	17.1	32.6	22.283	3.422
Left upper arm (mm)	31.5	355.0	299.397	49.829
Right upper arm (mm)	26.0	360.0	294.974	51.828
Left forearm (mm)	62.0	645.0	557.744	89.566
Right forearm (mm)	53.0	640.0	550.513	91.380
Left hand length (mm)	16.2	195.0	163.262	26.680
Right hand length (mm)	16.2	198.0	163.185	26.649
Left wrist (mm)	137.0	195.0	157.487	12.810
Right wrist (mm)	134.0	205.0	157.923	13.966
Left hand span (mm)	180.0	261.0	216.744	16.148
Right hand span (mm)	174.0	258.0	215.718	16.530
Sitting height (cm)	128.3	149.0	138.336	4.066
Head circumference (mm)	530.0	656.0	579.128	22.710
Neck circumference (mm)	294.0	470.0	356.795	41.379
Neck length (mm)	103.0	159.0	131.474	13.210
Shoulder width (mm)	353	500	423.53	35.619
Left shoulder height (mm)	488	635	559.72	34.287
Right shoulder height (mm)	476	630	555.00	33.697
Difference of R/L shoulder heights (absolute values) (mm)	0	23.00	8.0000	6.617
Bench height (mm)	463.0	560.0	505.039	17.322
Left pronation Range of Motion	47.4	126.2	74.579	17.592
Left supination Range of Motion	67.7	133.7	107.956	16.904
Right Pronation Range of Motion	53.3	125.6	78.346	15.494
Right Supination Range of Motion	70.1	154.6	117.867	18.316
Left pronation Speed	134	892	434.080	179.054
Left supination Speed	254	1154	618.770	240.811
Right pronation Speed	116	1190	474.050	211.896
Right supination Speed	213	1501	779.720	310.891

* BMI (Body mass index) = weight in kg/ (height in cm)^2 x 10.000.

As shown in Table 13, 89.7% of pianists were measured with varying shoulder heights. The mean difference of right to left shoulder heights was 8.0 mm (S.D. = 6.61mm) with maximum of 23 and minimum of 0. Thirty-seven (94.9%) of pianists are right handed. Twenty-four (61.5%) pianists have lower right shoulders, 28.2% with lower left shoulders, and 10.3% with the same height between right and left shoulders.

Table 13: Frequency of lower shoulders and hand dominance

Variables	Frequency	Valid Percent
Lower right shoulder	24	61.5
Lower left shoulder	11	28.2
Both same shoulder height	4	10.3
Right handed	37	94.9
Left handed	1	2.6
Both handed	1	2.6

Postural Measurement

Table 14 shows the grand means of defined angles. In general, the standard deviations of HN angles was the widest compared to other angles.

Table 14: Grand means and standard deviations of defined angles

Situations	Angles	Min	Max	Mean	S.D.
NSP	HN	157.15	222.75	206.925	12.855
	CT	160.26	176.56	167.708	3.922
	TL	152.66	179.00	169.200	6.000
	RSP	95.26	116.83	105.450	4.975
	LSP	93.62	115.47	104.590	4.971
	BT	78.92	95.05	84.394	3.407
Bach	HN	181.10	215.04	199.281	9.037
	CT	156.65	176.52	166.043	4.358
	TL	153.90	177.51	167.848	5.267
	RSP	96.23	116.54	106.979	5.036
	LSP	94.98	119.61	107.595	5.657
	BT	73.44	95.14	82.887	4.515
Mozart	HN	104.99	209.13	191.702	19.626
	CT	156.80	172.97	165.149	4.068
	TL	152.45	177.23	164.995	5.814
	RSP	97.28	115.71	107.337	4.422
	LSP	94.88	117.92	106.710	5.115
	BT	72.16	94.20	82.074	4.600
Grieg	HN	140.06	213.66	190.519	13.112
	CT	155.73	173.45	164.665	3.944
	TL	148.44	173.52	164.749	5.188
	RSP	101.10	118.81	110.058	4.511
	LSP	97.14	121.78	109.099	5.374
	BT	66.44	92.56	78.256	5.532
SR1	HN	194.48	225.29	209.818	7.933
	CT	159.67	173.84	166.389	3.963
	TL	153.49	178.31	165.462	5.829
	RSP	95.29	114.87	106.206	3.815
	LSP	94.20	117.62	106.431	5.311
	BT	74.03	92.17	81.149	4.346
SR2	HN	162.44	220.82	205.956	10.743
	CT	159.54	174.36	166.269	4.097
	TL	153.49	177.87	166.110	6.019
	RSP	97.12	115.70	108.068	3.721
	LSP	96.13	115.71	106.775	5.028
	BT	68.15	92.78	78.554	5.030

Figure 5 shows the grand means and confidence intervals (95%) for each of the defined angles. By observing each error bar across conditions, for all the angles other than shoulder protractions, the degree of angles in NSP are higher than other conditions. In contrast, RSP and LSP in NSP appear as the smaller angle degree. The degree of HN, CT, TL, and BT angles during performances by memory and sight-reading sessions have an inverse relationship such that these angles decrease as the level of difficulty of each piece increases. As opposed to HN, CT, TL, and BT, the degrees of RSP and LSP angles generally increase as the level of difficulty of each piece increases.

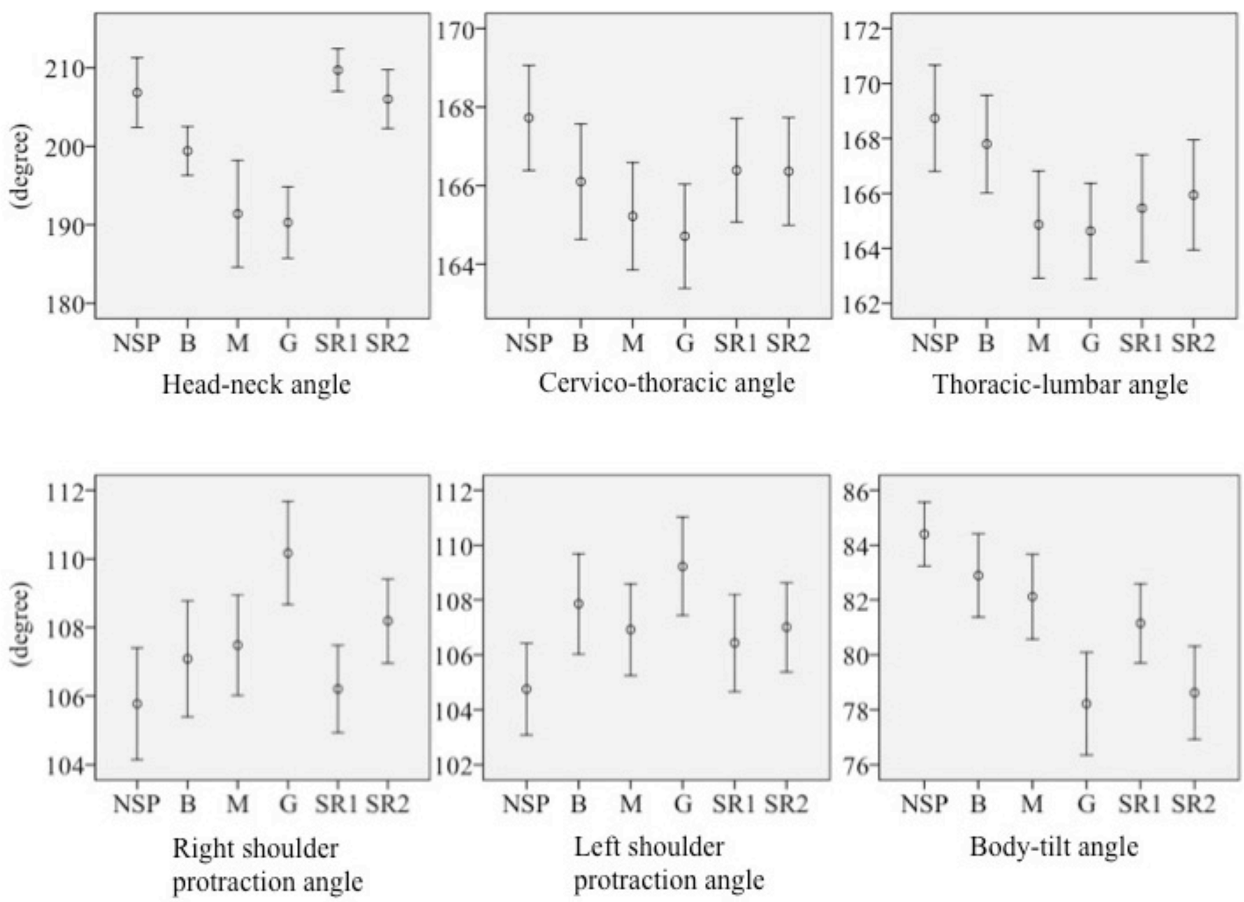


Figure 5: Grand means and standard deviations of the defined angles

Table 15 shows the mean and standard deviation of the angle differences between NSP and playing postures. Each angle during performances was subtracted by the corresponding angle in the NSP. If the resulting number is positive, that signifies the mean of HN angle in Bach is greater than the mean of angle in NSP. If the resulting number is negative, a mean of HN angle in Bach is smaller than the mean of angle in NSP. This table also shows that the HN angle difference in performances from NSP has the largest variation among pianists.

Table 15: Mean and standard deviation of angle differences of performances from NSP

Angles difference		Min	Max	Mean	S.D.
(B – N)	HN	-114.74	47.79	-15.161	24.958
	CT	-9.85	3.13	-2.524	2.935
	TL	-23.02	4.58	-3.992	4.968
	RSP	-5.54	10.00	1.671	3.525
	LSP	-5.48	7.98	1.964	2.857
	BT	-11.55	6.62	-2.287	3.787
[(M) - (N)]	HN	-72.07	30.34	-16.351	14.269
	CT	-11.26	3.41	-3.008	3.073
	TL	-29.43	3.87	-4.238	5.544
	RSP	-3.74	11.33	4.223	3.367
	LSP	-2.64	10.54	4.352	3.027
	BT	-16.64	4.99	-6.106	4.938
(G – N)	HN	-72.07	30.34	-16.351	14.269
	CT	-11.26	3.41	-3.008	3.073
	TL	-29.43	3.87	-4.238	5.544
	RSP	-3.74	11.33	4.223	3.367
	LSP	-2.64	10.54	4.352	3.027
	BT	-16.64	4.99	-6.106	4.938
(SR1 – N)	HN	-12.42	61.04	2.875	14.513
	CT	-6.74	4.00	-1.334	2.681
	TL	-13.87	6.07	-3.272	4.010
	RSP	-5.88	7.56	0.417	2.963
	LSP	-5.14	6.90	1.679	2.649
	BT	-12.56	4.60	-3.255	3.359
(SR2 – N)	HN	-56.36	52.10	-0.718	16.841
	CT	-8.97	4.85	-1.403	3.203
	TL	-13.38	6.91	-2.878	4.395
	RSP	-3.67	12.50	2.401	3.080
	LSP	-6.26	44.23	3.188	7.326
	BT	-14.24	5.20	-5.973	3.945

Comparing Neutral Seated Posture to Performance Postures

Table 16 shows paired samples *t*-test outcome of NSP versus angles in dynamic modes. Paired samples *t*-test showed that HN angles in Bach ($p < 0.005$), Mozart ($p < 0.001$), and Grieg ($p < 0.000$) were significantly different from the HN in NSP. The HN angles in NSP and both SR1 and SR2 did not show that they had significant differences. Since pianists look at music scores before them during the two sight-reading sessions, their HN angles are close to the ones in NSP. Pianists tend to have wider HN angles while playing sight-reading tasks than performances on three pieces by memory. Among the angles during three performance pieces of Bach, Mozart, and Grieg, the HN angles became smaller in order of Bach, to Mozart, to Grieg.

The CT angles in NSP and in other situations were different ($p < 0.05$). The TL in all the other situations except the one in Bach showed a significant difference ($p < 0.001$). The TL angle in Bach showed the widest angle among all the other angles; the one in Mozart showed the smallest angles. Means of TL angles in NSP, Mozart, Grieg, SR1, and SR2 were approximately the same. The BT angles during any situations including static and dynamic situations were different from the BT in NSP ($p < 0.05$).

The RSP angles in all the performances except for SR1 were significantly different from the RSP in an NSP. The left shoulder protraction angles in all the angles during performances were significantly different from the LSP in NSP ($p < 0.000$). Shoulder protraction angles can be measured by the degree of anterior movement of shoulders forward.

Table 16: Paired samples *t*-test outcomes of NSP versus angles in dynamic modes

Paired samples	Paired Differences					t	Sig. (2-tailed)
	Mean	S.D.	S.E.	95% CI			
				Lower	Upper		
Head-neck angles							
Pair 1 NSP - Bach	7.226	14.623	2.404	2.350	12.102	3.006	0.005
Pair 2 NSP - Mozart	15.161	24.958	4.103	6.840	23.483	3.695	0.001
Pair 3 NSP - Grieg	16.351	14.269	2.345	11.593	21.109	6.970	0.000
Pair 4 NSP - SR1	-2.875	14.513	2.418	-7.786	2.034	-1.189	0.242
Pair 5 NSP - SR2	0.718	16.841	2.768	-4.896	6.334	0.260	0.797
Cervico-thoracic angles							
Pair 1 NSP - Bach	1.629	2.901	0.470	0.676	2.583	3.463	0.001
Pair 2 NSP - Mozart	2.524	2.935	0.476	1.559	3.488	5.301	0.000
Pair 3 NSP - Grieg	3.008	3.073	0.498	1.998	4.018	6.034	0.000
Pair 4 NSP - SR1	1.334	2.681	0.440	0.440	2.228	3.026	0.005
Pair 5 NSP - SR2	1.403	3.203	0.519	0.350	2.456	2.701	0.010
Thoracic-lumbar angles							
Pair 1 NSP - Bach	1.139	4.681	0.759	-0.399	2.678	1.500	0.142
Pair 2 NSP - Mozart	3.992	4.968	0.806	2.359	5.625	4.953	0.000
Pair 3 NSP - Grieg	4.238	5.544	0.899	2.416	6.061	4.712	0.000
Pair 4 NSP - SR1	3.272	4.010	0.659	1.935	4.609	4.963	0.000
Pair 5 NSP - SR2	2.878	4.395	0.713	1.433	4.322	4.036	0.000
Body-tilt angles							
Pair 1 NSP - Bach	1.474	3.733	0.605	0.247	2.702	2.435	0.020
Pair 2 NSP - Mozart	2.287	3.787	0.614	1.042	3.532	3.723	0.001
Pair 3 NSP - Grieg	6.106	4.938	0.801	4.482	7.729	7.622	0.000
Pair 4 NSP - SR1	3.255	3.359	0.552	2.135	4.376	5.895	0.000
Pair 5 NSP - SR2	5.808	3.843	0.623	4.544	7.071	9.315	0.000
Right shoulder protraction angles							
Pair 1 NSP - Bach	-1.816	4.549	0.738	-3.312	-0.321	-2.462	0.019
Pair 2 NSP - Mozart	-2.175	4.810	0.780	-3.756	-0.594	-2.788	0.008
Pair 3 NSP - Grieg	-4.895	4.724	0.766	-6.448	-3.343	-6.388	0.000
Pair 4 NSP - SR1	-0.949	4.332	0.712	-2.393	0.495	-1.332	0.191
Pair 5 NSP - SR2	-2.905	4.477	0.726	-4.377	-1.434	-4.001	0.000
Left shoulder protraction angles							
Pair 1 NSP - Bach	-2.848	3.033	0.492	-3.845	-1.851	-5.788	0.000
Pair 2 NSP - Mozart	-1.964	2.857	0.463	-2.903	-1.025	-4.238	0.000
Pair 3 NSP - Grieg	-4.352	3.027	0.491	-5.347	-3.357	-8.864	0.000
Pair 4 NSP - SR1	-1.679	2.649	0.435	-2.562	-0.795	-3.855	0.000
Pair 5 NSP - SR2	-2.028	2.647	0.429	-2.898	-1.158	-4.723	0.000

Bivariate Correlations

Pianists' postures were correlated with all the examined intrinsic, extrinsic, and interaction factors: practice habits; piano-playing activity hours; piano-related experiences such as pain; performance anxiety, stress, and confidence level; mental and physical conditions; postural and body awareness; and anthropometric variables. Within all the correlation tables, only significant correlations at a level of less than 0.05 are shown. The correlations at a level of less than 0.01 are marked with two Asterisk symbols (**).

Posture vs. Pain from Online Baseline Questionnaire

Tables 17 shows correlations of postures versus pain factors from the online baseline questionnaire. Only HN, BT, the angle difference of HN from NSP, and the angle difference of BT from NSP showed correlations. CT, TL, RSP, and LSP did not show any correlations. "How often do you feel pain after playing piano?" is negatively correlated to the BT angles during Bach, Mozart, and SR1. The BT angle difference in any situation is negatively correlated to frequency of pain when playing and pain intensity. The pain questions from online baseline questionnaires are also positively correlated to HN of (G – N), (M – N), (SR1 – N), and (SR2 – N). In summary, these correlations show that the pianists indicated more frequent pain or higher pain intensity from the online baseline questionnaire when the BT angles are smaller during any playing situation and when the HN angles are wider during Grieg, Mozart, and sight-reading sessions.

Table 17: Postures vs. pain factors from online baseline questionnaire

Angles	Situations	"How often do you feel pain WHEN playing piano?"	"How often do you feel pain AFTER playing piano?"	"How often do you feel pain that stops you from playing piano?"	Pain intensity
BT angles	Bach		-0.372 0.021		
	Mozart		-0.389 0.016		
	SR1		-0.347 0.036		
Angle difference of BT angles from NSP	Bach	-0.353 0.030			-0.344 0.034
	Mozart				-0.329 0.043
	Grieg				-.0329 0.043
	SR1	-0.408 0.012			
	SR2	-0.391 0.015		-0.389 0.016	
Angle difference of HN angles from NSP	Mozart		0.411 0.011		
	Grieg			0.411 0.011	
	SR1	0.354 0.034			
	SR2	0.338 0.041			

Posture vs. Pain from Pre-and Post-Performance Questionnaires

Tables 18 shows correlations between posture and pain factors from pre- and post-performance questionnaires. HN angles in NSP were significantly correlated to the question of pain experience, "do you feel pain now?" from pre- and post-performance questionnaires (both pre- and post-q, p = 0.000). According to these correlations, the smaller the HN angles during

NSP, the more pain the pianists indicated in pre- and post-performance questionnaires before and after the trial performance. There were no significant correlations between pain and HN angles during Bach, Mozart, Grieg, SR1, or SR2.

The HN angles of (M – N) and (G – N) were positively correlated to pain experience from pre-performance questionnaire, suggesting that the larger the HN angles during Mozart and Grieg, the more pain the pianists indicated before the trial performance. Furthermore, the HN angles of (SR1 – N) and (SR2 – N) indicated strong correlations to pain experience both in pre- and post-performance questionnaires (both SR1 and SR2, $p = 0.000$). These high correlations on both SR1 and SR2 suggest that the larger HN angles during sight-reading sessions, the more pain the pianists indicated before and after the performance trial.

TL angles during all the performances except for Grieg were negatively correlated to pain experience from pre-performance questionnaire, indicating that the smaller the TL angles during these performances, the more the pain pianists indicated before the trial performance. The other angles that show one or two correlations to pain responses from pre-performance questionnaire are CT and RSP angles. In general, HN angles in NSP and HN angles of (SR1 – N) and (SR2 – N) showed highly strong correlations to responses of pain questions from the pre- and post-performance questionnaires ($p < 0.01$).

Table 18: Postures vs. pain factors from pre- and post-performance questionnaires

Angles	Situations	Pain experience (Pre-q)	Pain Intensity (Pre-q)	Pain experience (Post-q)	Pain Intensity (Post-q)
HN angles	NSP	-0.685** 0.000		-0.544** 0.000	
Angle difference of HN angles from NSP	Mozart	0.405 0.013			
	Grieg	0.405 0.013			
	SR1	0.735** 0.000		0.563** 0.000	
	SR2	0.603** 0.000		0.465** 0.004	
TL angles	NSP	-0.390 0.015			
	Bach	-0.333 0.041			
	Mozart	-0.373 0.021			
	Grieg				
	SR1	-0.378 0.021			
	SR2	-0.358 0.027			
	(SR1 – N)		-0.393 0.018		

Anthropometric Data vs. Pain

As shown in Table 19, pain questions are correlated to these variables: differences of both shoulder heights, upper arm length, forearm length, and hand length. No significant correlations were found between pain and height, weight, sitting height, neck circumference, or shoulder width. The postural characteristics of differences in shoulder heights indicated the strong, positive correlations with pain experience WHEN playing ($p = 0.005$), pain experience AFTER playing ($p = 0.015$), and pain experience before the trial performance ($p = 0.004$). These correlations indicate that the pianists who had more difference in shoulder heights reported more pain.

The correlations between hand size and pain are consistent, showing that a smaller hand size correlated with more pain, and thus corresponded to previous research.[40]

[40] Yoshimura, et al., 118-125.

Table 19: Correlations: Anthropometric data vs. pain

Factor	Left fore-arm length	Difference of shoulder heights	Left upper arm length	Right upper arm length	Right fore-arm length	Left hand length	Right hand length
Pain WHEN (OB-q)		0.445** 0.005					
Pain AFTER (OB-q)	-0.330 0.040	0.387 0.015	-0.357 0.026	-0.346 0.031	-0.331 0.040		
Pain intensity (OB-q)			-0.402 0.011	-0.396 0.013			
Pain experience (Pre-q)		0.456** 0.004			-0.382 0.017	-0.342 0.033	-0.359 0.025
Frequency of pain that stops playing	-0.494** 0.002						
Pain intensity (Pre-q)			-0.494** 0.002	-0.443** 0.005	-0.493** 0.002	-0.559** 0.000	-0.548** 0.000
Pain intensity (Post-q)	-0.444** 0.010		-0.444** 0.010	-0.419 0.015	-0.461** 0.007	-0.529** 0.002	-0.523** 0.002

Non-Posture-Related Variables vs. Pain from the Questionnaires

In this section, the correlations between pain versus the variables that will be analyzed with multiple linear regression later are described. As shown in Table 20, general stress, experience of tension before the trial performance, and finger and hands awareness while playing are correlated with responses to pain questions. These correlations suggest the positive relationship between general stress or tension before the trial performance and pain. Furthermore, results showed a negative correlation between fingers and hands awareness while playing and pain. Frequency of pain that stops a pianist from playing (OB-q), pain experience (Pre-q), and any of the pain questions from the post-performance questionnaire were not correlated to any of variables.

Table 20: Correlations: Non-posture-related variables vs. pain from the questionnaires

Pain (OB-q)	General stress	Do you feel tension now? (Pre-q)	Fingers and hands awareness
Pain WHEN (OB-q)	0.328 0.041	0.383 0.018	-0.320 0.047
Pain AFTER (OB-q)	0.343 0.033	0.416** 0.009	
Pain intensity (OB-q)		0.468 0.023	-0.347 0.031
Pain intensity (Pre-q)	0.370 0.022		

Posture vs. Piano Educational Background

HN angle during Mozart, BT during SR1, and RSP in NSP, Bach, Mozart, SR1, and SR2 showed positive correlations to piano educational background (Table 21). Among these correlations, BT during SR1 showed a positive correlation to total years of piano lessons (p =0.049). This correlation suggests that the shorter the total years of lessons, the smaller the BT angle during SR1. As described in the earlier section, which discusses the correlations between posture and pain, the BT angle during sight-reading was also correlated to pain. This correlation indicates that pain is associated with smaller BT angles during sight-reading. In addition, "total number of piano workshops participated" was correlated to HN difference from NSP during Mozart, which was positively correlated to frequency of pain experience AFTER playing piano and pain experience before the trial performance. Again, the larger HN angle during performance was found to be as possible risk factor within this study.

Table 21: Correlations: Posture vs. piano educational background

Piano educational background	RSP NSP	RSP Bach	HN Mozart	RSP Mozart	RSP SR1	BT SR1	RSP SR2
Total years of piano lessons	0.347 0.030				0.410 0.012	0.327 0.049	0.427** 0.000
Total number of medical treatments to PRMDs	0.373 0.019						
Total number of piano workshops participated		0.337 0.039	-0.595** 0.000	0.371 0.022			

Posture vs. Practice Habits

Table 22 shows the significant correlations of LSP during Bach, Mozart, and SR2 to "How often do you take break?." These data indicate the association between frequency of breaks taken during practice and the degree of left shoulders' protraction angles during Bach, Mozart, and SR2. In addition, "Do you take break during practice?" showed strong correlations to HN and BT angles during sight-reading sessions. Examinations of the correlations between the angle differences of HN and BT angles during sight-reading sessions from NSP suggest that the higher the score the pianists indicated to take a break during practice, the smaller HN angles or the larger BT angles that pianists recorded during sight-reading sessions, which were found to be related to less pain. There were no correlations found between posture and the questions "Do you warm up before you spend at piano?," Duration of break (min), and "Do you stop daily practice because you are mentally tired?."

Table 22: Correlations: Posture vs. practice habits

Practice habits	LSP Bach	BT Bach	LSP Mozart	HN SR1	CT SR1	HN SR2	LSP SR2
Time spent for warm up (min)					-0.337 0.041		
Do you take break during practice?				** -0.425 0.009		** -0.413 0.010	
How often do you take break during practice?	0.355 0.029		0.363 0.025				0.356 0.028
Do you stop daily practice because you are physically tired?		-0.362 0.026					

Practice habits	BT (B - N)	HN (SR1-N)	BT (SR1-N)	HN (SR2-N)
Do you take break during practice?	0.359 0.027	** -0.426 .0010	** 0.421 0.009	-0.414 0.011

Posture vs. Piano-Related-Activity Hours per Week

Table 40 shows various correlations among piano-related activities that pianists spend at piano per week versus posture. HN in NSP is negatively correlated to rehearsal and sight-reading hours, indicating that pianists who spend longer rehearsal or sight-reading hours per week showed smaller HN angles in NSP, which was found to be one risk factor for pain. HN angle difference from NSP and BT angle difference from NSP also showed strong correlations to sight-reading hours, showing that the longer the sight-reading hours that pianists spend per week, the smaller the BT, or the greater the HN angles that the pianists recorded during sight-reading sessions. As showed in the previous correlations between HN and BT during sight-reading sessions versus pain, the pianists who spend longer hours in sight-reading per week recorded the HN and BT angles during sight-reading sessions, which were found to be a risk factor for pain. Teaching hours and postures were not correlated.

Table 23: Correlations: Posture vs. piano-related-activity hours per week

Piano-playing activities	HN NSP	CT NSP	BT NSP	HN Bach	CT Bach	HN Mozart	HN SR1	TL SR1	BT SR1
N of performances								0.397 0.015	
Gig hour		-0.395 0.013	** 0.426 0.007		-0.363 0.025				0.367 0.026
Lesson hour						-0.358 0.027			
Practice hour	-0.368 0.023		0.363 0.023	-0.354 0.029					
Rehearsal hour	** -0.453 0.004								
Sight-reading hour				-0.388 0.016			-0.399 0.014		

Piano-playing activities	BT SR2	HN (B–N)	CT (B–N)	BT (B-N)	HN (N-M)	HN (N-G)	HN (SR1-N)	CT (SR1-N)
N of performances								** -0.446 0.006
Gig hour	** 0.415 0.010							
Lesson hour			-.0337 0.038					** -0.433 0.007
Practice hour		-0.341 0.039						
Rehearsal hour			-0.354 0.029					
Sight-reading hour				-0.349 0.032	0.369 0.025	0.369 0.025	** 0.517 0.001	

Piano-playing activities	TL (SR1-N)	RSP (SR1-N)	BT (SR1-N)	HN (SR2-N)	CT (SR2-N)	RSP (SR-N)	BT (SR2-N)
N of performances	0.371 0.024				-0.321 0.049		
Gig hour	0.367 0.026						
Lesson hour		-0.421** 0.010			-0.392 0.015	-0.336 0.039	
Practice hour	0.347 0.035						
Rehearsal hour			-0.568** 0.000	0.439** 0.007			-0.422** 0.008
Sight-reading hour							0.379 0.019

Posture vs. Stress, Performance Anxiety, and Confidence Level

The correlations between performance anxiety (P.A.) variables appeared to be related to mainly CT during Mozart, Grieg, and sight-reading sessions (Table 24). In addition, stress as pianist was correlated to CT during sight-reading sessions. These correlations indicate that the more stress, the more frequent P.A., or the higher P.A. level that pianists experience, the larger the CT angles pianists recorded. The correlations between stress, P.A. and confidence level and angles that were correlated to pain were not found. General stress and confidence as a pianist did not show any correlations to posture.

Table 24: Correlations: Posture vs. stress, performance anxiety, and confidence level

Stress and PA	BT NSP	CT Bach	CT Mozart	TL Mozart	CT Grieg	TL Grieg	BT Grieg	CT SR1	CT SR2
Stress as pianist								0.348 0.035	0.350 0.031
Frequency of P.A.	-0.319 0.048	** 0.420 0.009	** 0.462 0.004		** 0.417 0.009			** 0.421 0.009	** 0.470 0.003
Level of P.A.	-0.348 0.030	** 0.428 0.007	** 0.463 0.003		** 0.417 0.009			** 0.471 0.003	** 0.516 0.001
How much affected by P.A.				0.333 0.041		0.332 0.042	0.394 0.014		

Posture vs. Postural and Body Awareness

Awareness of muscle tension, muscle relaxation, and fingers and hands were correlated to postures (Table 25). Muscle tension awareness and fingers and hands' awareness showed the negative correlation to HN in SR1. Regarding HN in sight-reading, HN difference both in SR1 and SR2 from NSP were correlated to pain, suggesting that the larger the HN during sight-reading sessions, the more pain the pianists indicated. As previously discussed, fingers and hands' awareness were also negatively correlated to pain. Furthermore, the correlation between muscle tension awareness and HN in SR1 suggests that the more the pianists were aware of muscle tension or fingers and hands while playing, the smaller the HN in SR1 the pianists recorded. Muscle tension awareness is highly inter-correlated within a postural and body awareness factor. Therefore, a postural and body awareness and fingers' and hands' awareness may have positive affect to posture while playing.

Table 25: Correlations: Posture vs. postural and body awareness

Awareness	CT Grieg	RSP Grieg	HN SR1	HN (M-N)	LSP (M-N)	BT (M-N)	HN (G-N)	LSP (G-N)
Muscle tension awareness		0.338 0.038	-0.327 0.048	0.416 0.010		0.363 0.025	0.416 0.010	
Muscle relaxation awareness	0.378 0.019				-0.382 0.018			-0.382 0.018

Awareness	BT (G-N)	HN (SR1-N)	LSP (SR1-N)	LSP (SR1-N)	HN (SR2-N)
Muscle relaxation awareness	0.363 0.025				
Fingers and hands awareness		-0.403 0.015	-0.359 0.029	-0.359 0.029	-0.382 0.020

Posture vs. Variables from Pre- and Post-Performance Questionnaires

Physical and mental conditions before the trial performance showed many correlations to angles (Tables 26 and 27). Physical and mental tiredness before the performance was positively correlated to the HN in Grieg. The previous correlations also showed that the larger the HN angle during Grieg, the more the pianists complained of pain. This correlation suggests that the more the pianists felt physically or mentally tired before the performance, the larger the HN in Grieg the pianists recorded, which may cause pain. Furthermore, feeling tense and nervous showed strong, negative correlations to RSP both in NSP and during performances. According to these correlations, the more the pianists felt tense or nervous before the trial performances, the smaller RSP angles were recorded.

Table 26: Correlations: Posture vs. variables from pre-performance questionnaire

Pre-q	TL NSP	RSP NSP	BT NSP	HN Bach	RSP Bach	LSP Bach
Are you physically tired now?			0.337 .039	-0.387 0.016		
Are you mentally tired now?	0.345 0.034	-0.406 0.011	-0.407 0.011			-0.322 0.049
Do you feel any tension now?	0.331 0.042	** -0.476 0.003			** -0.457 0.003	-0.373 0.021

Pre-q	BT Bach	TL Mozart	RSP Mozart	HN Grieg	RSP Grieg	RSP SR1
Are you physically tired now?		0.357 0.028		0.403 0.012		
Are you mentally tired now?				0.355 0.029		
Do you feel nervous now?			** -0.499 0.001		** -0.508 0.001	** -0.450 0.005
Do you feel any tension now?	0.340 0.037					

Corresponding to the Pre-performance questionnaire, physical and mental conditions after the performance also showed correlations between shoulders. The only difference was that feeling nervous after the performance showed no correlations to posture, but to feeling cold. The colder the pianists felt, the smaller the degree of RSP (Table 27).

Table 27: Correlations: Posture vs. variables from post-performance questionnaire

	RSP NSP	HN Bach	CT Bach	RSP Bach	LSP Bach	BT Bach
Are you physically tired now?						** -0.342 0.036
Are you mentally tired now?		** -0.421 0.009	-0.345 0.034		-0.340 0.037	
Do you feel cold now?	** -0.466 0.003			** -0.435 0.006		

	RSP Mozart	RSP Grieg	RSP SR1	HN SR2	RSP SR2
Do you feel any tension now?				-0.325 0.046	
Do you feel cold now?	** -0.426 0.008	** -0.467 0.003	** -0.457 0.004		-0.388 0.016

Posture vs. Anthropometric Data

According to Table 28, weight was significantly correlated to TL angle in both static and dynamic situations. The heavier the weight, the smaller the thoracic-lumbar angles pianists recorded. Head circumference was correlated to CT angles in all the situations beside Mozart and Grieg, which are NSP, Bach, SR1, and SR2.

Table 28: Correlations: Posture vs. anthropometric data

Variables	NSP HN	NSP CT	NSP TL	NSP RSP	NSP LSP	NSP BT	B CT	B TL
Weight	-0.342 0.035		-0.395 0.013	0.389 0.014		0.319 0.048		** -.0497 -0.001
BMI*			** -0.422 0.007	** -.0422 0.010	0.320 0.047			
Head circumference		** 0.410 0.009			** 0.432 0.006		0.342 0.36	
Neck circumference			** -0.322 0.039			0.350 0.029		-0.357 0.028
Neck length								0.360 0.029

Variables	B RSP	B LSP	M TL	M RSP	G TL	G RSP	G LSP	SR1 CT
Weight	** 0.435 0.006		** -0.459 0.004	0.443 0.005	** -0.387 0.016	0.408 0.011		
BMI*	** 0.467 0.003	0.320 0.047	** -0.499 0.001	0.471 0.003	** -.0435 0.006	0.400 0.013	0.369 0.023	
Head circumference		** 0.432 0.006						0.412 0.011
Shoulder width				-0.337 0.041				

Variables	SR1 TL	SR1 RSP	SR1 BT	SR1 LSP	SR2 CT	SR2 TL	SR2 RSP	SR2 LSP	SR2 BT
Weight	-0.318 0.015	** 0.499 0.002				** -0.464 0.003	** 0.420 0.009		
BMI*	** -0.440 0.006	0.540 0.001				** -0.523 0.001	** 0.447 0.005		
Head circumference				** 0.520 0.001	0.392 0.015			** 0.043 0.005	
Neck circumference									** 0.438 0.006
Difference of shoulder heights			-0.341 0.039						

* Body Mass index, BMI = weight in kg/ (height in cm)^2 x 10,000.

Posture vs. Functional Capacity of Forearm Data

Functional capacity of forearm did not show as many correlations as the other correlations such as posture versus variables from the questionnaires and posture versus variables from the anthropometric data (Table 29). Left hand pronation of range of motion showed five correlations. CT during Bach and Mozart negatively correlated to Left hand pronation of range of motion. RSP during Grieg, SR1, and SR2 showed positive correlations with Left hand pronation of range of motion.

Table 29: Correlations: Posture vs. functional capacity of forearm data

Variables	NSP TL	Bach CT	Mozart CT	Grieg RSP	SR1 RSP	SR2 RSP
Left- P Range of Motion		-.0350 0.031	-0.382 0.018	0.355 0.029	0.366 0.026	0.350 0.031
Right – S Speed	0.375 0.019					

* P = pronation, S = supination

Linear Regression

Results showed that all analyzed regression models were statistically significant (p = 0.000) (Tables 30 and 31). The beta values associated with number of sight-reading hours were the largest followed by posture for each regression model. This finding suggests that sight-reading hours and posture were the strongest predictors for pain when compared to muscle tension, fingers and hands awareness, general stress, and hand and forearm lengths (Table 48).

Table 30: Regression models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Risk factor 1 (Posture)	HN SR1	HN SR1	Difference of shoulder heights	Difference of shoulder heights	Difference of shoulder heights	Difference of shoulder heights
Risk factor 2 (Sight-reading hour)	Sight-reading hour	Sight-reading hour	Sight-reading hour	Sight-reading hour	Sight-reading hour	Sight-reading hour
Risk factor 3 (Others)	Difference of shoulder heights	Tension (Pre-q)	Fingers and hands awareness	General stress	Right hand length	Right forearm length

Table 31: Regression data

	Predictors	Beta	Adjusted R^2	F	p-Value
Model 1			0.540	12.726	0.000
Factor 1	HN SR1	-0.236			
Factor 2	SR hour	0.742			
Factor 3	Shoulder heights	0.344			
Model 2			0.446	9.045	0.000
Factor 1	HN SR1	-0.193			
Factor 2	SR hour	0.740			
Factor 3	Tension	0.183			
Model 3			0.476	10.702	0.000
Factor 1	Shoulder heights	0.395			
Factor 2	SR hour	0.545			
Factor 3	Fingers and hands awareness	-0.060			
Model 4			0.486	11.098	0.000
Factor 1	Shoulder’s height	0.379			
Factor 2	SR hour	0.515			
Factor 3	General stress	0.122			
Model 5			0.518	12.473	0.000
Factor 1	Shoulder’s height	0.343			
Factor 2	SR hour	0.532			
Factor 3	Hand length	-0.213			
Model 6			0.529	12.996	0.000
Factor 1	Shoulder’s height	0.339			
Factor 2	SR hour	0.550			
Factor 3	Forearm length	-0.235			

Conclusions

Musicians suffer significant musculoskeletal problems, particularly associated with the upper extremities. The nature, magnitude, and causes of these problems are not well understood. Factors that can prevent and or reduce these problems are even less studied and reported. This study was conducted to address some of these issues. This study applied mixed methods (qualitative and quantitative measurements) combined with three-dimensional technologies to investigate the relationships between postures and pain. Specifically, this study examined correlations among pianists' postures and intrinsic, extrinsic, and interaction risk factors.

This study concludes that the degrees of head-neck and body-tilt angles and exposure time of piano-playing activities that involves reading music or sight-reading are important factors in the prevention of PRMDs. Therefore, the findings from this study support the hypothesis that practice and performance habits such as postures are correlated to piano playing-related injuries.

One of the most significant findings from this study is that the degrees of head-neck and body-tilt angles are likely risk factors for PRMDs. These findings are significant because head-neck and body-tilt angles are consistently and significantly highly correlated to pain. The degrees of HN and BT angles in two types of situations were related to pain. The first situation is in a static, neutral seated posture (NSP). The smaller HN angle occurs when the head tilts forward. Pianists who have smaller degrees of HN in NSP reported more experiences with pain. The second situation is in a dynamic position especially while pianists sight-read. During sight-reading, the degree of the BT angles was smaller than the BT angle in NSP. In other words, when compared to the BT angle in NSP, the whole body tends to tilt more forward while a pianist sight-reads. Correlation analyses revealed that the more the pianists tilt forward, the more pain the pianists experienced while playing. Furthermore, when the degree of the HN angle becomes larger while pianists sight-read, pianists tended to indicate more pain. While the HN angles during dynamic modes of performances on Mozart and Grieg were correlated with pain factors, the correlations with pain factors and the HN angles during sight-reading sessions were much stronger. These findings suggest that playing with a wider HN angle while the whole body tilts forward is a potential risk factor for PRMDs. This posture is associated with sight-reading. Supporting this conclusion, the pianists who have more opportunities to sight-read or to rehearse in chamber music or piano accompanying reported more PRMDs. This finding supports the previous suggestion that a forward head neck postures is a risk factor among musicians.[41]

In addition, the pianists with a greater height difference between both shoulders reported more pain. This finding suggests that the posture or the physical feature of having different shoulder heights may be an intrinsic factor that causes PRMDs in addition to the interaction factor of pianists' neutral seated or playing postures.

Furthermore, practice habits of taking breaks and awareness of body, hands, fingers, and postural awareness may have positive effects on those piano-playing postures that may already tend to cause more pain. Pianists who took breaks during practice more frequently showed smaller HN and greater BT angles during sight-reading sessions. In addition, pianists who were more aware of muscle tension, which was categorized into a body and postural awareness factor, showed smaller HN angles in sight-reading sessions compared to the HN angle in NSP. As previously discussed, wider HN angles and smaller BT angles during sight-reading session are risk factors. These findings suggest that taking more frequent breaks during practice and body and postural awareness could positively affect pianists' postures.

[41] Dommerholt, 404-405.

Limitation of the Study and Possible Future Investigations

A limitation of the study is that the measurement of postures was assessed only once. To minimize the repositioning error of postures, the number of postural measurements should be increased and it would be desirable to have six postural trials or more.[42]

In addition, previous literature measured head-neck angle by placing reflective markers on each canthus, located in the outer corner of the eye, and each tragus of the ear.[43] However, in this research, because of the limitation of the numbers of three-dimensional cameras, reflective markers on the tragus and the canthus were unable to be captured. Still, use of the occiput as a measure of head-neck posture has been reported using radiographic technique.[44] Therefore, to overcome the camera-driven technical challenge in my study, the canthus to tragus marker was substituted with the occiput marker.

Furthermore, data analysis from this study was based on the means of the angles of time-sequence while pianists were creating angles in movements. Analyzing the means of angles ignores variability in angles in time and misses the information on the tendency of how pianists are creating angles over time. To understand the change of angles in time and how this variability of pianists' angles affects PRMDs, further analysis, such as principal component analysis, should be implemented. Furthermore, the study on body movements, velocity, and

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[42] Gary Allison and Shioto Fukushima, "Estimating Three Dimensional Spinal Repositioning Error: The Impact of Range, Posture and Number of Trials." *Spine* 28 (2003): 2510-2516.

[43] Edmondston et al., 363-371; Leon Straker, et al., "Relationship Between Prolonged Neck/shoulder Pain and Sitting Spinal Posture in Male and Female Adolescents," *Manual Therapy* 14 no.3 (2009): 321 – 329.

[44] Howard W. Makovsky, "The Effect of Head Posture on Muscle Contact Position: The Sliding Cranium Theory," *The Journal of Craniomandibular Practice* 4 no.7 (1989): 286 – 292, Susan Armjio-Olivo, et al., "A Comparison of The Head and Cervical Posture Between The Self-balanced Position and the Frankfurt Method," *Journal of Oral Rehabilitation* 33 no.3 (2006): 194 – 201.

angles should be further investigated for understanding the relationship between pianists' posture in movements and the magnitude or nature of PMRDs.

Finally, this study was an exploratory research project and did not identify the range of the optimal or ideal angles that pianists would need to minimize pain and stress from their head, neck, and back during practice and performance. Therefore the further study should have as a result, the so-called best practices that will deliver the scientific identification and quantification of what are the best postures.

CHAPTER 4

DISCUSSION

Implications of Pianists' Health from the Findings of the Study

Based on the findings from this study, pianists play in rehearsals, including chamber and accompanying, for six hours, and sight-read for three and one-half hours per week on average, and some pianists spend their time in rehearsal for more than 20 hours and in sight-reading for more than ten hours per week. When they have rehearsals, situations may require pianists to sit at a piano for more than an hour without taking breaks. In previous literature, prolonged sitting was annotated as one of the risk factors for impairment and pain, and it was recommended that prolonged sitting be broken up by regular breaks at least once in sixty minutes.[45] In addition to the risk factor of prolonged sitting, pianists routinely encounter situations to sight-read, such as learning new music or accompanying piano. Considering the posture that pianists tend to create in sight-reading and the exposure time as a risk factor, it is essential for piano educators and health-promoters to acknowledge the importance of head-neck and whole body positions while playing the piano in addition to taking breaks at least once in an hour during playing or sight-reading. Knowledge gained from this study, which includes postural, body, hands, and fingers awareness as positive effectors of the pianist's posture, indicates that piano performers and educators would benefit from constant awareness and reminder of the muscle tension, muscle relaxation, body movements, postural, and fingers' and hands' awareness as well as the head and body positioning both in a static seated position and while playing the piano. This scientific-based study information could be incorporated into piano pedagogues or performer-education

[45] Stephano Bruno, et al., "Playing-related Disabling Musculoskeletal Disorders in Young and Adult Classical Piano Students." *International Archives of Occupational Environmental Health* 81 (2008): 8655-8860.

and awareness through the academic community for the prevention of PRMDs. Since the ideal ranges or movements of pianists' postures have not been identified, this current study can contribute to the research advances within this field such as establishment of best practice guidelines of pianists' postures. Such practices could bring great benefits among pianists.

APPENDIX A

ONLINE BASELINE QUESTIONNAIRE

Subject number

Drill down to answer

Age

Drill down to answer

Gender

Male	Female
○	○

Ethnicity-Race (Any possible)

African-American	Asian	Caucasian	Hispanic	Native-American	Other
☐	☐	☐	☐	☐	☐

Marital status

Single	Married	Separated	Divorced	Widowed
○	○	○	○	○

Number of children

Drill down to answer

Major/ Major of last degree

Accompanying	Classical performance	Composition	Jazz performance	Music education	Theory	Other (Please list)
☐	☐	☐	☐	☐	☐	☐

Degree

Bachelor	Master	Doctor	Non student
○	○	○	○

Approximate age you started playing piano

Years

Total number of years of piano lessons

Years

Hours you spent at piano today

(practice, lesson, rehearsals, performance)

Have you experienced any physical trauma or accident that affects your ability to play piano?

Yes	No
○	○

What kind of medical treatment or therapy have you had in response to piano playing-related problem?

None	Acupuncture	Chiropractic	Heat	Massage	Non-prescribed medication	Physician prescribed	Other (Please list)
☐	☐	☐	☐	☐	☐	☐	☐

What type of physical or technical-related piano workshops have you attended?

Alexander technique	Taubman approach	Other (Please list)
☐	☐	☐

Respond to the following questions based on your experience over the last 12 months.

Exercise

Hours per week

Sleep

Hours per day

Meal

Times per day

Number of performances (accompanying, competition, departmental, jury, recital)

Times per year

Gigs (church, restaurant, wedding, etc.)

Hours per week

Lesson

Hours per week

Practice

Hours per week

Rehearsals (chamber , accompanying)

Hours per week

Sight-reading

Hours per week

Teaching

Hours per week

Use your cursor to move the slider to indicate your answer on the scales below.

Do you warm-up before you spend time at piano?

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

How much time do you spend warming up?

Minutes

Describe your warm-up routine

Do you take breaks during practice?

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

How long are your breaks?

Minutes

How often do you take breaks?

Every ___ Minutes

Do you stop daily practice because you are physically tired?

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

Do you stop daily practice because you are mentally tired?

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10
Yes											

How often do you focus on the following when you play piano?

Posture

	Never									Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

Muscle tension

	Never									Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

Muscle relaxation

	Never									Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

Body movements

	Never									Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

Fingers/ Hands (Finger independence, sense of touch, playing close to keys, palm shape of hands, etc.)

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

Do you think you play piano with a good posture?

	Not at all										Best possible
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

How often do you experience pain WHEN playing piano?

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

How often do you experience pain AFTER playing piano?

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

How often does pain stop you from playing piano?

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10

Scroll											

Rate the level of the pain from playing piano.

	0	10	20	30	40	50	60	70	80	90	100
%											

Rate the level of your general stress.

	0	10	20	30	40	50	60	70	80	90	100
%											

Rate the level of your overall stress as a pianist.

	0	10	20	30	40	50	60	70	80	90	100
%											

When you play piano, how often do you experience performance anxiety (nervousness, stage fright, shaking, feeling cold, fast heart beating, stomachache, etc.)?

	Never										Always
	0	1	2	3	4	5	6	7	8	9	10
Scroll											

Rate the level of the performance anxiety when you play piano

	0	10	20	30	40	50	60	70	80	90	100
%											

Does performance anxiety affect your playing?

Negative impact — Not at all — Positive impact

	-5	-4	-3	-2	-1	0	1	2	3	4	5
Scroll											

Rate your level of confidence as a piano player

Not confident — Very confident

	0	1	2	3	4	5	6	7	8	9	10
Scroll											

>>

APPENDIX B

ANTHROPOMETRIC MEASUREMENT

PRE- AND POST-PERFORMANCE QUESTIONNAIRES

Anthropometric measurement

Pre and Post Questionnaires

Subject Number: _______________

Date: _________________________

Anthropometric Measures

1. Height _____ (cm)
2. Weight _____ (kg)
3. Hand Dominance (Circle) Left Right
4. Left upper arm length _____ (mm)
5. Right upper arm length _____ (mm)
6. Left forearm length _____ (mm)
7. Right forearm length _____ (mm)
8. Left hand length _____ (mm)
9. Right hand length _____ (mm)
10. Left wrist circumference _____ (mm)
11. Right wrist circumference _____ (mm)
12. Left hand span _____________(mm)
    Biggest intervals you think you can reach on keyboard _________ (th)
13. Right hand span ____________(mm)
    Biggest intervals you think you can reach on keyboard _________ (th)
14. Sitting Height _____ (mm)
15. Head circumference _____ (mm)
16. Neck circumference _____ (mm)
17. Neck length _____ (mm)
18. Shoulder width _____ (mm)
19. Shoulder Height Sitting Right_____ (mm) Left_____ (mm)
20. Bench height ______ (mm)

Basic Elements of Performance (BEP XII)

Range of Motion (deg)	Left side	Right side
	Pronation (CW) Supination (CCW)	Pronation (CCW) Supination (CW)
Rotation Speed (deg/sec)	Left side	Right side
	Pronation (CW) Supination (CCW)	Pronation (CCW) Supination (CW)

Pre-performance Questionnaire

1. Are you physically tired now?

   Not at all |———————————| A lot

2. Are you mentally tired now?

   Not at all |———————————| A lot

3. Do you feel nervous now?

   Not at all |———————————| A lot

4. Do you feel any tension?

   Not at all |———————————| A lot

5. Do you feel cold now?

   Not at all |———————————| A lot

6. Can you see well now?

   Not at all |———————————| A lot

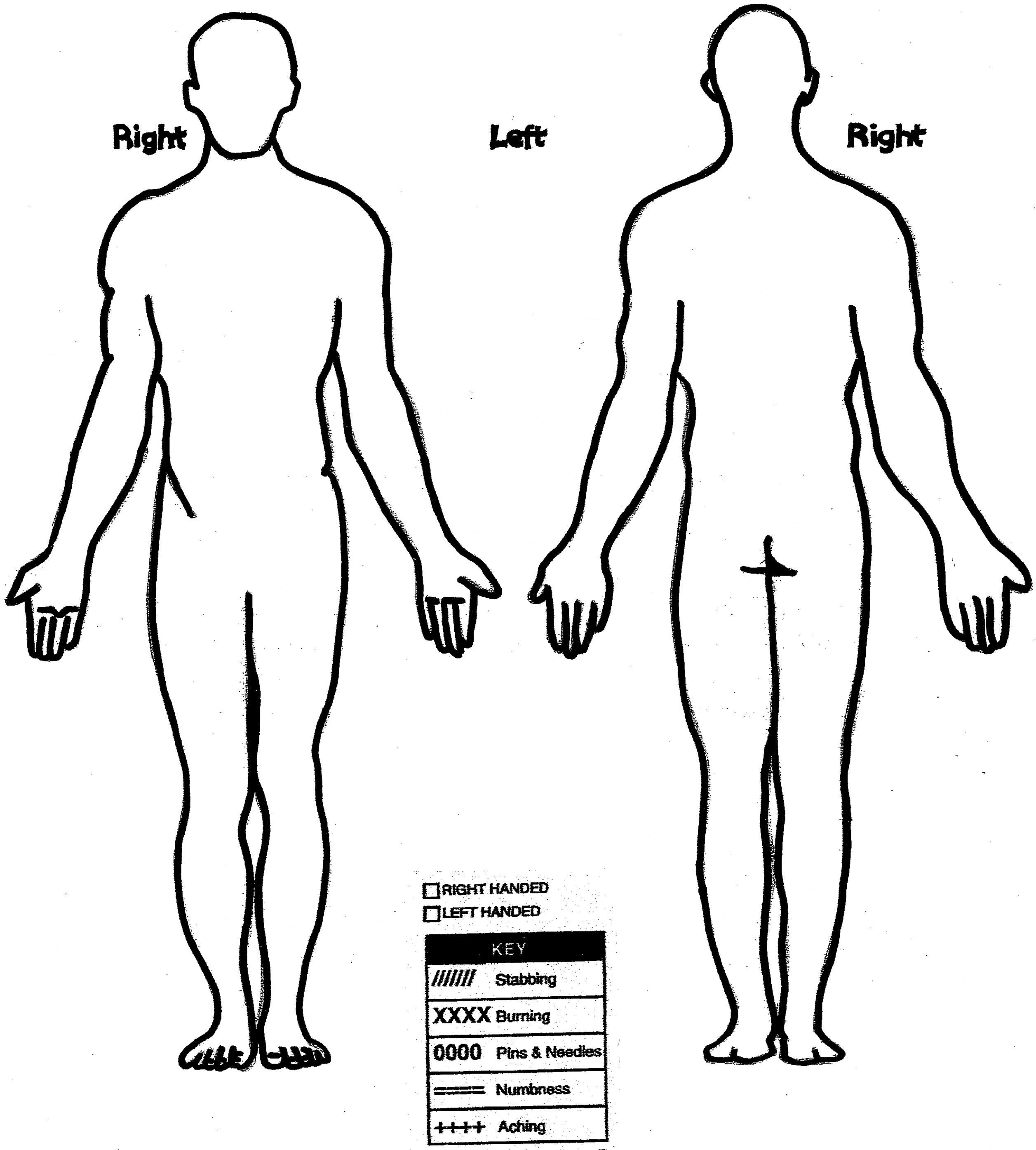
7. Do you feel pain now?

   Not at all |———————————| A lot

8. Please review the drawing on the next page and mark where you experience both current and past pain using the appropriate markings, as noted on the page, and rate the level of the pain from the 1 to 10.

****

Possible locations:
Right Fingers Left Fingers Right Wrist Left Wrist Right Forearm Left Forearm
Right Hand Left Hand Right Elbow Left Elbow Right Shoulder Left Shoulder
Right Neck Left Neck Right Upper Back Left Upper Back Right Middle Back
Left Middle Back Right Lower Back Left Lower Back Right Hip Left Hip
Right Knee Left Knee Right Calf Left Calf Right Ankle Left Ankle Right Foot
Left Foot Right Toes Left Toes


Right
Left
Right
☐ RIGHT HANDED
☐ LEFT HANDED
KEY
////// Stabbing
XXXX Burning
0000 Pins & Needles
===== Numbness
++++ Aching

Post-performance Questionnaire

1. Are you physically tired now?

   Not at all |———————————————| A lot

2. Are you mentally tired now?

   Not at all |———————————————| A lot

3. Do you feel nervous now?

   Not at all |———————————————| A lot

4. Do you feel any tension?

   Not at all |———————————————| A lot

5. Do you feel cold now?

   Not at all |———————————————| A lot

6. Can you see well now?

   Not at all |———————————————| A lot

7. Do you feel pain now?

   Not at all |———————————————| A lot

8. Rate the difficulties for the following pieces assiend for this research.

   J.S. Bach Prelude No.1 in C major from WTC Book I

   Not at all |———————————————| A lot

   Mozart Sonata No.16 in C major 1st movement

   Not at all |———————————————| A lot

   Grieg Piano Concerto in a minor, Introduction

   Not at all |———————————————| A lot

9. Rate the difficulty for the followings:

   1st sight-reading task for this research

   Not at all |————————————————————| A lot

   2nd sight-reading task for this research

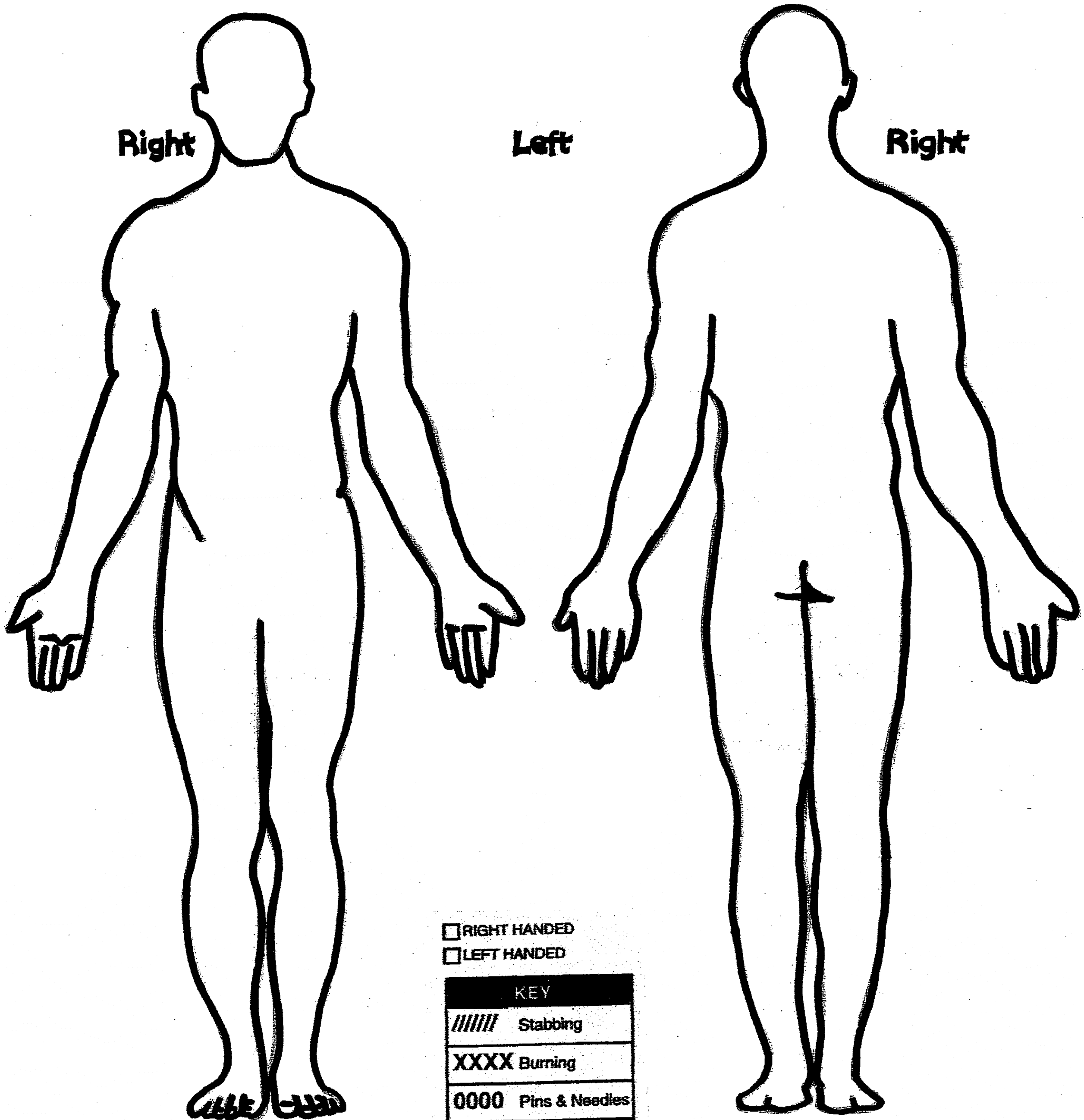
   Not at all |————————————————————| A lot

10. Please review the drawing on the next page and mark where you experience both current and past pain using the appropriate markings, as noted on the page, and rate the level of the pain from the 1 to 10.

****

Possible locations:

Right Fingers   Left Fingers   Right Wrist   Left Wrist   Right Forearm   Left Forearm
Right Hand   Left Hand   Right Elbow   Left Elbow   Right Shoulder   Left Shoulder
Right Neck   Left Neck   Right Upper Back   Left Upper Back   Right Middle Back
Left Middle Back   Right Lower Back   Left Lower Back   Right Hip   Left Hip
Right Knee   Left Knee   Right Calf   Left Calf   Right Ankle   Left Ankle   Right Foot
Left Foot   Right Toes   Left Toes



☐ RIGHT HANDED
☐ LEFT HANDED

KEY	
//////	Stabbing
XXXX	Burning
0000	Pins & Needles
=====	Numbness
++++	Aching

APPENDIX C

MUSICAL SELECTION 1

Prelude I

BWV 846

Johann Sebastian BACH
1685-1750
Urtext (ed. M.A. Caux)

APPENDIX D

MUSICAL SELECTION 2

Sonata No. 16
in C Major
K. 545

APPENDIX E

MUSICAL SELECTION 3

Allegro molto moderato

APPENDIX F

MUSICAL SELECTION 4

1ST SIGHT-READING PIECE


210
sfz
sfz
mf
217
222

APPENDIX G

MUSICAL SELECTION 5

2nd SIGHT-READING PIECE


48
5
52
fff
55
ff

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