Detection of Forearm Muscle Fatigue during Piano Playing Using Surface Electromyography (sEMG) Analysis

by

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Abstract

Musculoskeletal injuries of the forearm, wrist, and hand are a significant problem for pianists. Approximately 60% of piano players experience playing-related injuries at some point in their careers; yet, the cause of injury is not well understood. Muscle fatigue may be a contributing factor. The focus of this work was to determine if muscle fatigue is detectable in the forearm muscles used for piano playing, if there is a difference in the development of muscle fatigue between pianists and non-pianists, and if there is an effect on how a pianist plays when their muscles are fatigued. A piano exercise and fatiguing exercise protocol were established and 11 pianists and 6 non-pianists were tested. It was hypothesized that pianists would show less incidence of fatigue than the non-pianists due to adaptations in muscle structure and task performance strategies. Results confirmed that muscle fatigue is detectable in the forearm muscles, but there was no evidence that muscle fatigue was more likely to occur in one group or the other during the fatiguing exercise. However, there were differences noted in the development of muscle fatigue between pianists and non-pianists. Strong evidence of muscle recovery was shown in the extensor muscles of the pianists during the second and third piano exercise. As well, comparisons between the pianists and non-pianists showed significant differences in the flexor muscles; during the second piano exercise all of the non-pianists exhibited muscle fatigue, whereas the majority of the pianists showed muscle recovery.

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List of Abbreviations

A/D	Analog-to-Digital
BPM	Beats per Minute
CNS	Central Nervous System
DAQ	Data Acquisition
ECR	Extensor Carpi Radialis (muscle)
ECU	Extensor Carpi Ulnaris (muscle)
EDC	Extensor Digitorum Communis (muscle)
EMG	Electromyography
FCR	Flexor Carpi Radialis (muscle)
FCU	Flexor Carpi Ulnaris (muscle)
FDS	Flexor Digitorum Superficialis (muscle)
FFP	Five Finger Pattern
FFT	Fast Fourier Transformation
LFF	Low Frequency Fatigue
MDF	Median Frequency
MES	Myoelectric Signal (synonymous with EMG signal)
MIDI	Musical Instrument Digital Interface
MNF	Mean Frequency
MUAP	Motor Unit Action Potential
NI	National Instruments
PRMD	Playing-Related Musculoskeletal Disorder

PAP	Post-Activation Potentiation
PSD	Power Spectral Density
RMS	Root Mean Square
sEMG	Surface Electromyography
SENIAM	Surface EMG for the Non-Invasive Assessment of Muscles
SNR	Signal-to-Noise Ratio

1 Chapter: Introduction

1.1 Motivation

Pianists are typically not considered to have a dangerous occupation.^{1,2} However, playing an instrument (especially at a professional level) is an activity comparable to strenuous athletic endeavours, causing high physical load and risk of musculoskeletal disorders.^{2,3,4} Researchers have reported that more than sixty percent of active piano players have suffered from playing-related musculoskeletal disorders (PRMDs) at some point in their careers.^{5,6,7} PRMDs lead to a loss of practice time, often become chronic, and can be career-ending.^{1,2,8,9,10} PRMDs affect all aspects of life and are devastating to pianists physically, emotionally, socially, and financially.^{1,2,3,9,10} Several studies have attempted to determine risk factors for PRMDs, but a clear and indisputable cause of playing-related injury has not been established.^{7,11} Detecting manifestations of muscle fatigue during piano playing, using surface electromyography (sEMG), may be useful in determining the effect that piano playing has on the musculoskeletal system, for the clinical management of piano players, and to facilitate injury prevention strategies.

1.2 Objectives

There are three main objectives of this work: 1) to determine if muscle fatigue is detectable in the forearm muscles used for piano playing, 2) to determine if there is a difference in the development of muscle fatigue between pianists and non-pianists, and 3) to verify if there is an effect on how a pianist plays when their muscles are fatigued.

1.3 Contributions

An effective and repeatable piano exercise and fatiguing exercise methodology was established, providing the opportunity to compare pianists and non-pianists while performing the same (or similar) tasks. As well, the research involved the creation of an extensive dataset, which can be used for future research.

There has been limited research conducted on pianists. Studies conducted by Penn et al. and Lai et al. (described in section 2.6) compared muscle fatigue in the first dorsal interosseous muscle of pianists and non-pianists. However, detection of muscle fatigue in the forearm muscles during piano playing has not been substantiated. Thus, this research is novel, because (to my knowledge) there has not been any other study conducted looking at muscle fatigue in the forearm muscles during piano playing.

This study is rare because it examined forearm muscle activity using frequency spectrum analysis. Previous research using sEMG to examine forearm muscle activity has mostly focused on the comparison of amplitude parameters and the activities being tested are typically grasping or finger tapping tasks.

Few studies have analyzed forearm muscle fatigue during dynamic conditions even though they provide better insight into non-stationary activities, such as activities of daily living, and repetitive tasks. This research examined muscle activity during dynamic activities during the fatiguing exercises and during piano playing.

1.4 Thesis Outline

This thesis consists of seven chapters and is organized as follows:

Chapter 2 presents a background of relevant anatomy and physiology of the forearm, wrist, and hand. It details the literature related to the effect of piano playing on the musculoskeletal structures, the effects of muscle fatigue, and the use of sEMG for the detection of muscle fatigue.

Chapter 3 outlines the methodology used for the investigation of muscle fatigue. It provides details of the selection criteria for participants in the study, the equipment and setup used for the acquisition of electromyography (EMG) signals, the activities the participants performed during the EMG signal acquisition, and the processing techniques used to organize and analyse the data collected.

Chapter 4 provides the results and analysis of the fatiguing exercise performed by the participants.

Chapter 5 provides the results and analysis of the piano exercise performed by the participants.

Chapter 6 provides the results and analysis across all of the activity units performed by the participants.

Chapter 7 presents a summary of the results, conclusions drawn from the analysis of the findings, and recommendations for future work.

2 Chapter: Background and Literature Review

2.1 Introduction

The human body is a complicated biomechanical system. Any study of its movement requires an understanding of the relationship between the motion of limbs, the muscles that create that motion, and the complex system of nerves that control the motion.¹² This chapter presents a background of relevant anatomy and physiology of the forearm, wrist, and hand, the effect of piano playing on these structures, the development and effects of muscle fatigue, and the use of sEMG for the detection of muscle fatigue.

2.2 Anatomy and Physiology of the Wrist and Hand

The hand is primarily used for manipulation activities that require fine motor control and a variety of hand and finger positions.¹³ Movement of the hand requires many complex muscle and joint actions, and there is a significant relationship between the position of the wrist and the efficiency of finger actions.¹³ Figure 2.1 illustrates the anatomical location of bones in the wrist and hand.¹⁴

Figure 2.1: Bones in the wrist and hand
A – Palmer View; B – Posterior View

The wrist is a kinematically complex joint that involves the relative motion of several articulating joints.¹⁵ One of these joints is the radiocarpal joint; it is the articulation where movement of the entire hand occurs and includes the distal end of the radius and the proximal row of carpal bones.¹³ There are two rows of carpal bones and the articulation between these two rows is classified as the midcarpal joint.¹³ Movement of the hand in flexion and extension is initiated at the midcarpal joint.¹³ Adjacent to the radiocarpal joint is the distal radioulnar articulation (also called the ulnarcarpal space), but there is not any contact between the ulna and the carpals because it is separated by a fibrocartilage disc.¹³ The radioulnar articulation is not involved in wrist movement, but it is important for the rotation of the hand in pronation and supination.¹³ The hand can also move laterally in ulnar and radial deviation and these movements are possible because the proximal row of carpals glides over the distal row.¹³ Figure 2.2 illustrates the numerous joints of the wrist and hand.¹⁴

Figure 2.2: Joints in the wrist and hand
A – Palmer View; B – Posterior View

The position of the hand and forearm bones in relation to one another, and the intricate system of forearm muscles is what contributes to the hand's remarkable mobility.¹⁴ Most of the muscles responsible for the active control of the wrist and hand originate outside of the wrist/hand region and connect to the hand via long tendons that cross the wrist.¹³ Damage to any one of these muscle tendons can significantly impair wrist motion.¹⁴

Muscular control is necessary for both mobility and stability during functional hand and wrist activities.¹⁴ Active motion of the hand and wrist is controlled by the coordinated action of both extrinsic and intrinsic muscles; movement is achieved because of their arrangement in agonist-antagonist pairs.¹³ Wrist motion is essential for enhancing the fine motor control of the fingers and hand because the position of the wrist affects the ability of the fingers to flex and extend to their maximum capability.¹⁴ There are two agonist-antagonist pairs of muscles that control extension and flexion of the hand at the wrist, and additionally these muscles are responsible for radial and ulnar deviation of the hand; these muscles are the Extensor Carpi Ulnaris (ECU) and Flexor Carpi Ulnaris (FCU) and the Extensor Carpi Radialis (ECR) and Flexor Carpi Radialis (FCR).¹⁴ Four additional muscles control pronation and supination of the forearm; these are listed in a table with all of the forearm muscles and their functions in Appendix A. A diagram with anatomical terms for wrist and hand movements is also included in Appendix A.

The strongest muscles in the hand region, and capable of the greatest work capacity are the Flexor Digitorum Superficialis (FDS), FCU, Extensor Digitorum Communis (EDC),

Flexor Pollicis Longus, ECU and ECR.¹³ Figures 2.3 and 2.4 show the anatomical location of the forearm muscles in both anterior and posterior views.¹⁶

Figure 2.3: Anterior view of the forearm muscles

Figure 2.4: Posterior view of the forearm muscles

It is believed that the human hand evolved primarily for grasping tasks and studies have shown that the strength of the flexor muscles is over twice that of the extensor muscles.^{14, 17, 18} However, when examining the motion of the wrist during activities of daily living (eating, drinking, grooming, etc.), it has been shown that nearly all continuous tasks require only extension of the wrist.¹⁴ Hand dominance (the preferential use of one arm during motor tasks) also impacts how activities requiring movement of the hand and wrist are performed since the dominant hand is typically used to perform these activities.¹⁹ Variations in anatomy from one person to another can also create biomechanical differences that impact which muscles and joint postures are used to perform a desired activity.¹³

2.3 Structural Organization of Skeletal Muscle

Voluntary muscle contraction results from a sequence of events, with each event having the potential to limit force generation.²⁰ The first process involves all central factors that influence the activation of the motor neurons such as motivational factors and sensory information (temperature, pain, motivation, etc.). The electrical impulses (action potentials) that travel along the motor neurons to each neuromuscular junction (synapse) are included in this process.²⁰ Each motor neuron and all of the muscle fibers (muscle cells) that it innervates make up a motor unit, and skeletal muscle only contracts when these cells are stimulated by the motor neuron.²¹ Figure 2.5 shows the basic anatomy of skeletal muscle and the components of a motor unit.²¹ See Figure 2.7 for a more detailed schematic of the structural organization of skeletal muscle.

Figure 2.5: Basic anatomy of skeletal muscle

When a motor neuron is stimulated, an action potential is transmitted across the neuromuscular junction (also called the motor unit end plate), depolarizing the cell membrane.¹⁴ The resultant depolarization opens voltage-gated calcium ion channels and transmitter molecules are released into the synaptic cleft.²¹ These molecules open transmitter-gated channels generating a strong inflow of sodium ions and a weak outflow of potassium ions, depolarizing the postsynaptic muscle cell membrane (sarcolemma) and creating a flow of equalizing currents toward adjacent non-depolarized regions.^{21, 22} The propagating action potentials move further into the muscle cell by depolarizing the transverse tubule system and open voltage-gated calcium ion channels in the storage vesicles (sarcoplasmic reticulum) which release calcium ions into the cytoplasm.²¹ Figure 2.6 shows an example the reactions occurring at a neuromuscular junction.²¹

Figure 2.6: Example of reactions occurring at a neuromuscular junction

The increased level of calcium ions in the cytoplasm stimulates contraction of the myofibrils within the muscle cell by allowing binding of the myosin filaments to the actin filaments via cross bridges.²¹ Cross bridges between the filaments cause the thin filaments (actin) to slide over and between the thick filaments (myosin), and this sliding filament mechanism shortens the successive sarcomeres.²¹ The sarcomere is the functional unit of the contractile system in the muscle and the events that occur in one sarcomere are duplicated in the others.¹⁴ A muscle fiber contracts when all sarcomere shorten simultaneously.¹⁴ Detailed schematics of the anatomy of skeletal muscle as well as the components of the sliding filament mechanism are provided in Figure 2.7.¹⁴

Figure 2.7: Schematic drawing of the structural organization of skeletal muscle and the sliding filament mechanism

When the muscle cell is no longer stimulated, the voltage-gated calcium ion channels close and the calcium ions are removed from the cytoplasm.²¹ This causes the contraction of the muscle cell to stop and the muscle to relax and return to its original length by elastic recoil.²¹

There is an approximately 3-10 ms latency period between stimulation of the motor unit (with the arrival of an action potential) and the contraction of the muscle cell (through the release of calcium ions); this delayed contraction is called a muscle twitch.²³ Increasing the frequency of successive action potentials reduces the relaxation time between twitches and the twitch duration will get shorter causing twitches to summate and

produce a sustained and prolonged muscle contraction (tetanus).²¹ Different motor units have to be asynchronously activated to attain a smooth muscle contraction so the central nervous system (CNS) regulates muscle force production by varying the recruitment of new motor units and changing the firing rates of active motor units.²⁴ Figure 2.8 illustrates the contraction of a muscle fiber in response to a train of action potentials.²¹

Figure 2.8: Contraction of a muscle cell in response to a train of action potentials
Image (a) shows the action potentials with a varying firing rate (instantaneous frequency) and image (b) shows the summation of twitches to reach tetanus.

The number of muscle fibers forming a motor unit is related to the degree of control required by the muscle.¹⁴ Large and small muscles differ in the number of muscle fibers they contain as well as firing rates and fiber type; For example, small muscles that perform fine movements may contain less than a dozen muscle fibers, whereas large muscles that perform gross motor skills can contain 1000-2000 muscle fibers.^{14, 25}

Muscle fibers are categorized depending on their speed of contractile twitch. The three main fiber types are: type I (slow-twitch, oxidative), type IIA (fast-twitch, oxidative/glycolytic) and type IIB (fast-twitch, glycolytic).^{14, 20, 26} Most muscle tissues contain a mixture of both slow twitch and fast twitch muscle fibers.^{14, 26}

During a muscle contraction, the sequence of recruitment of muscle fibers is determined by their threshold for activation with usually the smallest, most fatigue-resistant motor units being recruited first (in accordance with the “size principle”) to avoid physiologic fatigue.^{20, 26, 27, 28} Different muscle fiber types have different energetic and contractile properties and muscles with a large percentage of slow-twitch fibers have shown to have better endurance than those with more fast-twitch fibers.²⁹ However, an often overlooked aspect of muscle endurance is whether or not the CNS uses a motor control strategy to reduce fatigue, which makes the motor unit activation pattern one of the most complicating factors of fatigue studies.^{20, 29}

2.4 Muscle Fatigue

Fatigue is a common experience in everyday life, but the processes involved in determining the presence of muscle fatigue are still not entirely understood.^{20, 30, 31}

Muscle fatigue is generally considered to be a weakness in the muscles resulting in a decline in overall muscular performance.^{26, 31} Repetitive or intense activity can lead to muscle fatigue, and fatigue is usually evident when muscles are no longer able to exert force normally or when greater effort than normal is required to exert a desired level of force.²⁷ From a physiological perspective, muscle fatigue is defined as the physiologic

and biochemical changes that occur within a muscle motor unit resulting in its inability to maintain a contraction.^{27, 28} For example, during a sustained maximal contraction, force will steadily decline, and fatigue can be observed from the start of the exercise.²⁰

However, if submaximal contractions are generated (such as in everyday activities) performance may be maintained at the target intensity for a long period time and the onset of fatigue may not limit the ability of an individual to perform a task.^{20, 31}

Additionally, intermittent activity is unlikely to hinder the blood supply to the point of oxygen depletion to the muscles, so it is possible for altered physiological processes to occur without changes of the properties at the cellular level.²⁰

Over the past few decades, researchers have worked to develop methods for the identification and quantification of muscle fatigue. The literature on muscle fatigue provides several different views on the most important mechanisms for fatigue as well as other processes associated with the development of fatigue.²⁰ Numerous studies have used exercise models involving maximum voluntary contractions, nerve stimulation and ischemic conditions; however, it is difficult to compare the results of one study to another because of the wide range of exercise models and different methods applied to fatigue studies.²⁰ As well, due to the variability of muscle characteristics from one person to another there is no simple function of muscle load or timing to define a muscle fatigue threshold.²⁸

It is challenging to determine the origin of muscle fatigue because it is such a complex process and involves both central and peripheral factors.^{28, 32} Central fatigue relates to

the CNS and involves connections from the brain to the nerves involved in the muscle contraction.²⁸ Changes to various neurotransmitters in the brain produce a reduction in nerve-based motor signals to the muscle, which results in decreases in the voluntary activation of the muscle due to decreases in the number of motor units recruited and decreases in their discharge rate.^{28, 33, 34} Peripheral factors of muscle fatigue occur in the contracting muscle and include increases in metabolite concentrations and exhaustion of metabolic reserves (such as the depletion of glycogen), and inadequate perfusion of the muscle tissue.^{25, 28} Peripheral factors alter neuromuscular transmission and action potential propagation (seen by the reduction in intramuscular conduction velocity), which results in decreases in contractile strength of the muscle fibers, and ultimately the ability of the muscle to exert force.^{28, 34, 35}

Peripheral fatigue is the most common cause of physical fatigue, but is dependent on the type of contraction.^{28, 31} Both central and peripheral fatigue occur during sustained maximal muscle contraction, but during submaximal contractions more peripheral fatigue is present than central fatigue.²⁸ Furthermore, because every day activities and repetitive tasks use low-force submaximal contractions, low frequency fatigue (LFF) (where motor units are recruited and used at low frequencies (1-20 Hz)) is likely to be present.³⁶

The CNS does not develop unique solutions to motor control problems, but instead develops families of solutions based on the specific functionality needed to perform a task.^{30, 37} Numerous degrees of freedom are possible (such as various combinations of joint postures) and if a movement error is introduced (such as the reduced capacity of

fatigued muscles), other elements may compensate for that error in order to maintain performance of the targeted goal.^{30, 37} Krugar et al.³⁷ examined the effects of muscle fatigue on error compensation strategies during multi-finger ramp force production. They found that decreased contributions from one finger did not significantly impair the other fingers' ability to compensate for errors, but impaired interactions among all four fingers resulted in significantly decreased ability to compensate for errors during a four-finger fatiguing exercise. Similar to findings by Danion et al.³⁸ and Danion et al.,³⁹ their observations indicate task dependent central reorganization by the CNS after fatigue, and error compensation preservation among the fingers.

The study conducted by Gates and Dingwell³⁵ looked at nine muscles in the upper extremity during a repetitive task to quantify how muscle fatigue affected task performance. Similar to Krugar et al.,³⁷ their study illustrated the preservation of task performance through altered biomechanical movement patterns in response to muscle fatigue.

Fatigue of a single muscle group may cause changes in muscle activation patterns or imbalances between agonist-antagonist pairs of muscles.⁴⁰ To compensate for decreased feedback and delayed responses the body can increase muscle co-contraction to increase joint stiffness to maintain stability.⁴⁰ When high precision is required for a task, the body compensates by increasing limb stiffness such that performance can be maintained, but at the expense of a higher workload (greater energy requirements) of the muscles involved.⁴¹ Not all individuals increase co-contraction as a response to muscle fatigue,

but when co-contraction is used to maintain joint stability it can initiate a vicious cycle of needing increased muscle activity, which further accelerates fatigue.^{40, 41}

Since muscle function is essential for stability, any factors affecting muscle responses can alter the local stability (the ability of the body to correct small perturbations quickly, without tissue damage).⁴² Muscle fatigue causes decreased proprioception, which results in a decrease in one's accuracy of perception of movement or position of body parts.^{40, 41} Muscle fatigue also increases muscle response times, alters reflexes and changes muscle activation patterns (potentially causing poor biomechanics), which can also lead to functional instability and increase risk of injury.^{42, 43}

Proper movement timing is essential to the execution of motor tasks and muscles need to be activated or inactivated in both the correct sequence and at appropriate times.³⁵

Muscle fatigue can alter muscle timing and coordination, but how muscle fatigue affects the control and timing of the muscles during repetitive tasks (such as playing piano) has not been established.^{30, 35, 42}

2.5 Electromyography

Surface electromyography (sEMG) is a safe, easy, and non-invasive method that allows for the measurement of muscle activity.^{25, 44} When performing sEMG, electrodes are placed on the surface of the skin to pick up the electrical activity (action potentials) produced by the superficial muscles below them; the EMG signal generated is then amplified by the EMG equipment so that it can be shown on a display.^{25, 45} EMG signals

can also be detected invasively using needle (fine wire) electrodes. Needle electrodes are capable of reaching deeper muscle layers, and provide greater spacial selectivity (recording fewer muscle fibers) than surface electrodes.^{22, 25} However, they were not desirable to use in the application of this research as they are more susceptible to motion artifacts than surface electrodes, can be painful, and pose a risk of infection.²⁵

As described in section 2.3, during a muscle contraction, action potentials are produced by each motor unit; it is the superposition of these motor unit action potentials (MUAPs) that is captured in the EMG signal.^{25, 46} Figure 2.9 illustrates how an EMG signal is formed by the superposition of MUAPs and captured by a surface electrode.⁴⁷

Figure 2.9: EMG signal formed by the superposition of MUAPs of two motor units (a) shows two motor units with muscle fibers parallel to the skin below a surface electrode (b) shows the action potentials of the individual fibers and their summation to form a MUAP and (c) shows a train of MUAPs forming a typical EMG signal.

The EMG signal is stochastic with a noise-like appearance because the MUAPs have both positive and negative components, variable firing rates, and are usually recruited in an asynchronous pattern.^{25, 48} Motor units are recruited based on size, with the smallest muscle fibers and motor units recruited first followed by the recruitment of larger muscle fibers and motor units if the synaptic signal continues.²⁵ The firing rate of muscle fibers is usually in the range of 8-50 Hz, and as the exertional demands of the muscle increase, the firing rate moves from lower to higher frequencies.²⁵

If the contraction of a muscle is sustained or repeated over a long enough period of time, the muscle can fatigue and the conduction velocity of the action potentials along the muscle fibers will begin to decrease.²⁵ This causes the muscle to lose its ability to sustain the contraction at the same level.²⁵ Normal voluntary muscle activity, such as that during activities of daily living, is generally characterized by low motor neuron firing rates (10-20 Hz) with only partial summation of muscular force.²⁰ Submaximal contractions such as these complicate fatigue studies because only a fraction of the total motor units are used for a muscle contraction.²⁰

The EMG signal is closely related to the size and activity of the muscle being measured and is illustrative of the functional state of the muscle fibers.⁴⁹ During voluntary muscle contraction, motor unit recruitment and discharge rates dictate the temporal and spectral properties of the EMG signal.⁵⁰ The strength of the muscle contraction is indicated by measurements of the EMG signal amplitude in the time domain (such as the root-mean-square (RMS)), and is influenced by motor unit recruitment and firing rate modulation.^{45,}

^{46, 49, 50, 51} However, even though EMG signal amplitude increases concurrently with the increase in contractile force of a muscle, these measurements typically only vary in sympathy with one another; they are rarely linearly proportional. ^{22, 25}

Amplitude measurements are primarily used as a means for providing biofeedback so that athletes, musicians, and persons undergoing rehabilitation can learn to control the level of muscle tension (activation) in various parts of their body. ⁵² Biofeedback studies have been used to address the activation of opposing muscles (agonist-antagonist muscle pairs) to encourage more efficient muscle activation through the avoidance of simultaneous activation (co-contraction). ⁵² Zinn and Zinn ⁵³ used biofeedback on pianists to alleviate playing-related pain through training of the forearm muscles. Research conducted by Anderson, ⁵⁴ examined co-contraction and active muscle stiffness in a variety of piano playing tasks and determined that even though participants of the study perceived an uncomfortable increase in stiffness at the wrist, there was only a measured increase in fifty percent of cases. Therefore, perceived stiffness from co-contraction may have been related to the presence of muscle fatigue.

When analysing EMG signals, myoelectric manifestations of muscle fatigue become evident because the signals undergo temporal and spectral changes. ^{44, 50} Increased amplitude of the EMG signal has been associated with muscle fatigue, ^{44, 55, 56} but the literature also shows contradictory results where the amplitude decreases. ^{20, 57, 58, 59, 60} EMG amplitude values are therefore not a reliable indicator for the detection of muscle fatigue and are rarely used as an index of the fatigue process. ^{20, 58, 59, 60}

The downward shift (towards lower frequencies) in the power spectrum of the EMG signal has proven to be the hallmark for detection of muscle fatigue.^{32, 51, 55, 61, 62} These spectral changes are generally attributed to a progressive decrease in the muscle fiber action potential conduction velocity, but also the synchronous firing of motor units, recruitment of new motor units and a shift in dominance from fast-twitch to slow-twitch muscle fibers.^{25, 55, 63}

The process of spectral analysis begins by transforming the EMG signal from the time domain to the frequency domain.⁴⁸ Fourier transform techniques are used to decompose the EMG signal into its frequency components. The frequency spectrum shows the distribution of energy versus the frequency of the original signal. By squaring the amplitude of the frequency spectrum, the power spectral density (PSD) is produced and plotted to show the frequency components of the EMG signal as a function of the probability of their occurrence.^{25, 48}

Changes in mean frequency (MNF) and median frequency (MDF) of the power spectral density curve are common variables used in movement analysis for examining the frequency shift during fatiguing muscle contractions.^{26, 28, 32, 34, 44, 55, 59, 61, 63, 64} MNF of the power spectrum is defined in equation 2-1 and MDF in equation 2-2.

$$f_{mean} = \frac{\int_0^{\infty} f \cdot P(f) df}{\int_0^{\infty} P(f) df} \quad (2-1)$$

$$\int_0^{f_{med}} P(f) df = \int_{f_{med}}^{\infty} P(f) df = \frac{1}{2} \int_0^{\infty} P(f) df \quad (2-2)$$

MDF is defined as the frequency that splits the power spectrum of the EMG signal in half and is the preferred variable for spectral analysis as it has shown to be less susceptible to noise than the MNF, particularly during low activation levels when the signal-to-noise ratio (SNR) is low.^{63, 65, 66, 67}

In addition to noise, there are several other factors that can impact the quality of the EMG signal. The thickness of the fatty subcutaneous tissue between the muscle and the recording electrodes, the locations of the active motor units within the muscle, and the length and orientation (i.e., pennation angle) of the muscle fibers can have a relatively large influence on both the amplitude and frequency components of the surface EMG signal.^{33, 60, 68} Skin preparation, and electrode size, shape, spacing, and placement can also influence the reliability of the EMG signal.⁶³

Electrode placement is critical to ensuring reliable and repeatable results because electrodes placed near the muscle tendons or innervation zones can cause attenuation of the EMG signal.^{28, 34, 68} Additionally, it is important to place electrodes in such a way that minimizes interference (crosstalk) from nearby muscles, which can distort the interpretation of the EMG signal.^{28, 34, 69} The close proximity and small size of the forearm muscles make locating and testing them difficult, and conclusions about the contribution of the individual muscles needs to be made cautiously.^{25, 49, 69}

Some researchers have criticized Fourier-based methods and the use of center frequencies (MNF and MDF values) in identifying muscle fatigue from EMG signals due to their

susceptibility to movement artifacts and spectral interpretations.^{32, 61, 70} Fast Fourier Transformation (FFT) is the most common procedure for tracking time-dependent changes in frequencies, but has limitations because the window lengths (time segments) used for analysis are user-defined.⁶¹ Shorter segments have better time resolution, but poor frequency resolution, whereas longer segments have the opposite effect.⁶¹ Thus, the window lengths used in frequency analysis need to be as long as possible.⁶⁵

Research conducted by Hollman et al.⁶¹ showed that FFT window lengths did influence MDF variability, but that the slopes were equivalent across five different processing conditions and that the FFT window length had minimal influence on the MDF slopes. As well, research conducted by Beck et al.⁷¹ (comparing FFT and wavelet transform procedures) and Clancy et al.⁶⁵ (comparing FFT and time-varying autoregressive methods), showed that both methods provide similar information regarding the physiological mechanisms causing muscle fatigue, and that Fourier-based methods are acceptable for determining patterns of MNF and MDF during both static and dynamic fatiguing muscle contractions.

Numerous studies have characterized the changes in spectral parameters using short-duration sustained isometric-isotonic (static) contractions for the evaluation of muscle fatigue.^{34, 56, 72, 73} An advantage of using isometric contractions, as illustrated in Figure 2.10,⁷² is that it is possible to distinguish between metabolic fatigue (indicated by declining MDF) and contractile fatigue (indicated at the point force output declines). Isometric contractions are considered stationary with a Gaussian distribution of the EMG

signal and are easier to record than dynamic contractions because there is not any movement of the underlying muscle fibers with respect to the recording electrodes.^{34, 63, 70, 73} As well, during dynamic contractions the non-stationarity of the EMG signal is increased by the rapid changes in recruitment and de-recruitment of motor units.^{34, 60, 70}

Figure 2.10: Plot showing the distinction between metabolic and contractile fatigue

There are four time-varying factors that impact the non-stationarity of an EMG signal: the number of active motor units, the firing rate of active motor units, muscle force, and joint angle.^{62, 74} All of these factors impact the muscle's action potential conduction velocity, but variation in joint angle has shown to have the most significant effect on the center frequencies (of the power spectrum of the EMG signal).⁷⁴ Joint angle during dynamic contractions is therefore an important factor to regulate if muscle fatigue is to be predicted, since it can impact the MDF results without the presence of muscle fatigue.

Despite the non-stationarity of the EMG signal recorded during dynamic exercises, and conflicting results of the effects of dynamic contractions on power spectrum center

frequencies, some researchers have demonstrated the validity of using dynamic contractions while assessing muscle fatigue.^{42, 62, 65, 67, 74, 75, 76}

Theoretical and experimental work conducted by MacIssac et al.,⁶² Cechetto et al.,⁷⁴ and Zaman et al.,⁷⁶ showed that the number and firing rate of active motor units does not significantly affect the MNF during fatiguing dynamic contractions providing the joint angle and muscle force remained consistent across the sequential EMG signal segments analysed. These studies illustrate that MNF (or MDF) is a viable fatigue index for dynamic contractions under constrained conditions (such as cyclic contractions), but degrade as contractions become more random.

Highly standardized cyclostationary conditions help to overcome the stationarity requirements of FFT methods because it is assumed that the cyclic task results in nearly identical changes in muscle force, muscle length, and velocity of shortening/lengthening of the muscle fibers.^{67, 70, 77} When it is assumed that these factors are invariant for the biomechanically repeatable portions of each cycle, then the changes in the time-frequency spectrum of the EMG signal should be closely related to the spectral compression resulting from muscle fatigue.^{67, 77}

Few studies have analyzed forearm muscle fatigue during dynamic conditions even though they provide better insight into non-stationary activities such as piano playing. Detecting manifestations of muscle fatigue during piano playing is important for determining the effect piano playing has on the musculoskeletal system.

2.6 Effect of Piano Playing on the Musculoskeletal System

Playing piano is one of the most complex tasks the human body can perform and places an extremely high demand on the musculoskeletal system.⁷⁸ Learning how to play the piano takes many years and hours of practice to perfect, and involves a broad range of body movements.^{5, 17} Piano playing typically uses the smaller muscles within the hand and forearm to provide greater fine motor control, but evidence has shown that the larger muscles of the forearm are also being utilized.¹⁷ Most of the work in playing the piano is borne by the upper extremity and consequently the most common sites of playing-related musculoskeletal disorders (PRMDs) are the forearm, wrist, and hand.^{10, 79, 80}

To play the piano, the angle of the wrist needs to be adjusted in flexion and extension, as well as abduction and adduction (radial and ulnar deviation) so that the fingers can reach and depress the piano keys.^{81, 82} Each movement direction causes co-activation of agonist-antagonist muscle pairs, and because wrist flexors have a greater moment arm than the extensor muscles, larger forces are required by the extensor muscles to maintain the wrist posture.⁸³ Maintaining the wrist in a deviated posture requires greater muscle activity (as compared to the neutral position), which can lead to muscle fatigue.^{81, 83}

These additional demands on the forearm flexor and extensor muscles, and deviating the wrist towards the limit of its range of motion, increases the risk of injury.^{17, 81, 82, 83}

One issue for pianists is that piano teaching is steeped in tradition: piano teachers teach the way they were taught and their teachers were taught.⁸¹ Piano teachers have learned recommended wrist positions and movement techniques throughout their careers, but

generally an individual's performance is based on the musical results of the movement, and not the biomechanics required to produce it.⁸¹ How much load occurs on the upper extremity during high-level performance, or how much risk the wrist and forearm muscles are placed under when a pianist plays with biomechanically detrimental wrist positions, has not been conclusively determined.⁸⁴ According to ergonomic literature, it is less demanding to keep the wrist in a neutral position; however, maintaining a neutral posture can greatly reduce the speed of piano playing when movements are required in multiple directions, or to accelerate and decelerate tempo.⁸¹

Typically piano training includes the development of finger dexterity, but also the development of musical expression, and avoidance of excessive tension through the “economy of movement”.⁸⁵ Practice sessions are devoted to skill acquisition rather than strength training of the muscles, as would be required in typical athletic training.¹⁷ However, piano training can create metabolic adaptations of the muscles and possible differences in muscle fiber composition.⁶⁶ Despite the high level of variability between individuals in a population, findings show that deconditioned (untrained) individuals use a higher level of muscle activity to exert the same amount of force as a person with trained muscles.^{25, 66, 86}

Similar to athletes, long-term piano training can induce biochemical and structural adaptations to the muscles of the forearm and hand, and changes to the nervous system's motor control strategy.^{66, 86, 87} Athletic endeavours often require rapid production of powerful movements, whereas piano playing requires fine motor control of submaximal

movements.^{4, 86} For this reason, pianists are often regarded as 'small muscle athletes' or 'instrumental athletes' undertaking endurance rather than power activities.^{4, 66, 86}

Penn et al.⁶⁶ were the first to investigate whether pedagogical training in pianists could be categorized as aerobic or anaerobic. They compared a group of pianists with a control group of non-pianists, and using frequency domain analysis (via EMG), investigated if piano training produced any sequential changes in their first dorsal interosseous muscles. They found that during a fatiguing exercise, the MDF shifted towards lower frequencies in both the pianist and control groups, but subsequent to fatigue, the MDF was significantly lower than before fatigue in the control group. They also found that significantly longer time was needed to induce fatigue in the pianists. It was concluded that piano training increases endurance due to training-induced metabolic adaptations in the muscles of the pianists.⁶⁶

In the study conducted by Lai et al.,⁸⁶ it was thought that the training of a pianist group (that practiced at least 2-4 hours per day) may induce both strengthening and endurance effects. When the first dorsal interosseous muscles of a pianist group were compared to a control group of non-pianists, physiologic adaptations were shown by the pianists' superior coordination and motor control. The pianists demonstrated significantly higher firing rate, shorter duration, and higher amplitude of the MUAPs during minimal muscular contractions than the control group.⁸⁶ These findings further illustrate physiologic changes that can occur through the muscular training of playing piano.

There are three phases of the physiologic changes that occur in exercise training: motor planning neural adaptations, increase in muscular strength, and increase in both muscular size and strength.⁸⁶ When a person first learns to play the piano, a large portion of the motor cortex of the brain is used for motor planning in the CNS.^{86,88} Each time the task is performed, similar memory occurrences are recovered. The neural adaptations in this phase include increased motor unit discharge rates (in long-term not short-term training) and result in higher MUAP amplitudes.⁸⁶

After many years of piano playing, and repeatedly stimulating the same region of the body, a much smaller region of the motor cortex is devoted to finger dexterity as the brain has strengthened the related synapses (and inhibited those from non-essential motor functions), and needs fewer neurons to perform the same task.⁸⁸

In the second phase of training, there is an increase in muscle strength without an increase in the muscle's anatomic cross-section, whereas in the third phase there is an increase in both muscular strength and size.⁸⁶

Playing the piano (especially at a professional level) is an activity comparable to strenuous athletic or fitness training. Long periods of practice may enhance strength and aerobic capacity of specific muscles, but repetitive and forceful motions can also overload both the aerobic (oxidative) and anaerobic (glycolytic) energy systems and increase the risk of injury.^{2, 3, 66}

2.7 Injuries of the Forearm, Wrist and Hand in Piano Players

Injuries of the forearm, wrist, and hand are a significant problem for pianists.^{5, 6, 7, 8 10, 79, 80, 89} Researchers have reported that more than sixty percent of active piano players have suffered from PRMDs at some point in their careers.^{5, 6, 7} PRMDs refer to muscle, nerve, bone, and joint problems such as tendonitis, bursitis, nerve entrapment, and joint degeneration, and their severity can range from mild aches and pains to swelling, weakness, lack of fine motor control (diminished accuracy), numbness, tingling, loss of response (diminished agility and speed), and other disabling symptoms.^{2, 4, 81, 90, 91, 92, 93} Pain is always the predominant symptom reported,^{4, 79, 80, 92} and due to the repetitive submaximal nature of piano playing, any damage to the muscles, tendons, or joints may not be apparent and can accumulate over time.^{1, 2, 5, 6, 85}

PRMDs often become chronic (lasting 2-5 years on average), and in addition to affecting playing piano, they have also been shown to impair domestic activities, leisure time activities, and sleep.^{2, 3} PRMDs are devastating to musicians physically, emotionally, socially, and financially and can be ultimately be career-ending.^{1, 2, 4, 8, 9, 10}

A number of predisposing risk factors of the development of PRMDs have been identified in the literature. These include: instrument played,^{5, 10, 81, 89, 92, 93} gender,^{3, 5, 10, 81, 89, 92, 93} age,^{2, 81, 92, 93} anatomical differences (including smaller hands, joint structure, tendon linkages),^{2, 10, 82, 92, 94, 95, 96} intensity and duration of practice,^{4, 10, 80, 81, 90, 92, 93} technique (biomechanics),^{6, 7, 10, 81, 82, 90, 92} muscle conditioning,^{10, 92} and years of experience.^{5, 81, 89} The instrument specific risks of the piano include: repetitive

movements, playing posture, and the force required to depress the piano keys.^{10, 80, 94, 97}

Piano playing techniques related to a higher incidence of PRMDs include: octaves, chords, trills, arpeggios, fortissimo, presto, staccato, and wide extent passages.^{6, 7, 80, 91, 94, 95, 96} Lederman⁹² also found that symptoms were more often on the right side of pianists.

Changes in the normal routine of practice and performance such as a sudden increase in practice time, difficult/demanding repertoire, change of instructor, and non-musical activities (such as typing and writing) are also risk factors.^{4, 10, 82, 85, 89, 90, 91, 93} Increased levels of psychological stress have also been identified as a significant risk factor towards developing PRMDs.⁹⁸

The study conducted by Yoshie et al.,⁹⁸ looked at how social-evaluative performance situations affect the subjective, autonomic, and motor stress responses in pianists. When under stress, the pianists showed higher EMG amplitude levels in proximal muscles (biceps brachii and upper trapezius), and co-contraction of antagonistic muscles in the forearm (EDC and FDS) when in a competitive situation. Although these responses can be interpreted as integral components of the 'fight or flight' defense mechanism, they can adversely affect pianists by increasing their muscle activity, causing muscles to fatigue at a faster rate, disrupting their fine motor control, and increasing their risk of injury.⁹⁸

Grieco et al.,⁹⁷ used EMG to investigate the relationship between music practice and PRMDs among piano students. Analysis of muscle activity during piano exercises

revealed an excessive static and median loading of certain muscular structures, especially of the epicondyle muscle group of the forearm.

The most common injury among pianists is lateral epicondylitis.^{84, 94} Lateral epicondylitis is associated with overuse of the wrist extensor muscles, and it is thought that the repetitive motion of piano playing puts a large amount of stress on the extensor muscles.^{13, 84} As well, the extensor muscles are used more than the flexor muscles for wrist stabilization, which puts greater strain on the lateral side of the elbow joint.^{13, 18, 83}

The study by Sakai and Shimawaki,⁹⁶ compared 220 pianists with overuse disorders and 62 unaffected pianists by using radiographs to examine abduction angles of the thumb and little finger, hand span, and length of the fingers. Pianists who suffered from lateral epicondylitis showed significantly smaller hand span and finger length, but no difference in abduction angle of the thumb and little finger. It was concluded that pianists with smaller hand span and finger length are particularly at risk of developing lateral epicondylitis because they have a greater tendency to overuse the long extensor muscles of the forearm.^{94, 96}

Decreased muscle endurance may also be related to development of lateral epicondylitis. Rojas et al.⁹⁹ compared the activation patterns of wrist extensor muscles during isometric contractions in normal subjects and those with a history of lateral epicondylitis. Differences in wrist extensor muscle co-activation pattern were found during selective actions and wrist extension. Patients who had a history of lateral epicondylitis showed

lower ECR activation and higher ECU activation as well as a significantly higher fatigue index. It was not possible to determine if the biomechanical deficits occurred because of the injury or preceded the injury and contributed to it, but it was concluded that detecting these biomechanical deficits is critical to the design of rehabilitation and injury prevention programs.⁹⁹

Lateral epicondylitis may also occur because of an imbalance between the activation of the forearm flexor and extensor muscles.^{18,99} Similar to Rojas et al.,⁹⁹ Shimose et al.¹⁸ showed that patients with lateral epicondylitis had weaker ECR activation when compared to healthy subjects. Wrist extension training was shown to improve the imbalance between forearm flexor and extensor muscles by increasing the activation of the ECR and ECU, and decreasing the activation of the FDS and FCU. Therefore, wrist extension training may be beneficial for the prevention of forearm injuries.¹⁸

An interesting finding, from the study conducted by Ranelli et al.,⁹³ was that playing multiple instruments was found to be protective against PRMDs; the opposite result was expected due to the increased exposure time required for practice. It was suggested that the protective association of this outcome may be comparable to cross-training in athletics (which has also been shown to have protective properties).²

Although numerous studies have shown a strong association between risk factor exposures and the precipitation of injury, a clear and indisputable cause of playing-related injury has not been established.^{7,11} One factor that makes it difficult to establish

a cause and effect relationship is the tissue's ability to adapt and recover from stress exposure.¹¹ Differences between individual's anatomy and movement pattern further compound this challenge.

Use of electromyography (EMG) to analyze muscle activity during piano playing increases the ability to determine biomechanical factors that influence the physiological load on the upper extremity.⁷ If muscle fatigue is quantified, it may be possible to determine more efficient means of practice and decrease the possibility of injury.

2.8 Summary

It is well known that the power spectral density of the EMG signal undergoes frequency compression during sustained muscle contractions.⁵⁶ Detecting these manifestations of muscle fatigue during piano playing is of interest because of the potential application of monitoring muscle condition using non-invasive muscle assessment. sEMG is also considered the most suitable method for non-invasive analysis because it contains both the central and peripheral factors of muscle fatigue.^{28, 32, 33, 46, 56}

Fatigue assessment during dynamic tasks (particularly prolonged isotonic exercises of moderate intensity), is of more relevance to activities of daily living and occupational functions because of their non-stationarity.^{73, 74, 75} The assessment of muscle fatigue provides insight of: basic physiology, ergonomics, diagnosis of disease, occupational and rehabilitative medicine, and performance of athletes and musicians.^{32, 33, 43, 44}

3 Chapter: Experimental Approach

3.1 Introduction

This chapter outlines the methodology used for the investigation of muscle fatigue during piano playing. The focus of this work was to determine if muscle fatigue is detectable in the forearm muscles used for piano playing, if there is a difference in the development of muscle fatigue between pianists and non-pianists, and to verify if there is an effect on how a pianist plays when their muscles are fatigued. Experimental testing and data collection was conducted at the University of Ottawa Piano Pedagogy Research Laboratory. This study was approved by the Carleton University Research Ethics Board and the University of Ottawa Research Ethics Board.

3.2 Participants

This research involved two participant groups: 1) the Pianist Group and 2) the Control Group. For the Pianist Group, eleven participants meeting the following inclusion criteria were recruited for the study: 1) 18 years of age or older; 2) more than 15 years of piano playing experience or studying piano at a university undergraduate or graduate level; 3) have not had any known injuries or pain associated with piano playing.

Six participants for the Control Group were also recruited, but one person's EMG data did not record properly and had to be discarded. These participants met the same age requirement as the Pianist Group, had no piano playing experience or less than a year of

piano playing experience, and had no known current or past forearm injuries or forearm pain when completing tasks of daily living or typing.

Written consent was obtained from each participant. Each participant was assigned a general alphanumerical identification so that their identity would remain confidential.

The participants in the Pianist Group were also asked to complete a general information questionnaire regarding their piano playing practice schedule and experience. After reading and signing the letter of information and consent forms, the testing procedure was explained to the participants and they were given the opportunity to ask questions. The letter of information, consent form, and questionnaire are in Appendix B. Questionnaire responses and a table with the participant demographics can be found in Appendix C.

3.3 Equipment

The Delsys[®] Bagnoli[™]-8 Desktop EMG System (Delsys[®] Inc., Boston, MA) was used to acquire EMG data. Surface electrodes in a bipolar (single differential) configuration (Delsys[®] DE-2.1) were used to detect the EMG signals from the muscles of the participants. Each Delsys[®] DE-2.1 sensor consists of two 99.9% silver, parallel bar electrodes measuring 10 mm by 1 mm and spaced 10 mm apart. Figure 3.1 illustrates the geometry of the Delsys[®] DE-2.1 sensor.¹⁰⁰

Figure 3.1: Delsys[®] DE-2.1 sensor geometry

The output voltage of the EMG signals, measured on the skin's surface (above the selected muscles) by each sensor, was determined by taking the potential difference between the two voltage measurements from each electrode (V_1 and V_2). Figure 3.2 clarifies the calculation of the output voltage measured by each sensor.¹⁰⁰

Figure 3.2: Calculation of the output voltage from each single differential sensor

The sensors were connected to the main amplifier unit by an input module and were amplified by a gain of 1000. Figure 3.3 shows the connection of one sensor to the input module and main amplifier unit.¹⁰⁰ Full specifications for the Delsys[®] Bagnoli[™]-8 Desktop EMG System and Delsys[®] DE-2.1 sensor can be found in Appendix D.

Figure 3.3: Components of the Delsys[®] Bagnoli[™]-8 Desktop EMG System (power source, main amplifier unit, sensor input module, and DE-2.1 sensor)

The main amplifier unit was designed to filter the EMG signals to a bandwidth between 20 Hz and 450 Hz, and to check for excessive amounts of line interference and channel clipping (due to over-amplified signals).¹⁰⁰ The analog voltage signals outputted by the

Delsys[®] Bagnoli[™]-8 Desktop EMG System were retrieved through the connection of a high-density D-Sub HD68 Connector attached to the rear panel of the main amplifier unit and wired to a National Instruments (NI) USB-6009 analog-to-digital (A/D) data acquisition (DAQ) device (National Instruments Corporation, Austin, TX). EMG signals were collected at a sampling frequency of 1000 Hz, in the ± 5 V range and at a 14-Bit resolution. Delsys[®] EMGworks 4.1.1 software (Delsys[®] Inc., Boston, MA) was used to control the acquisition of the EMG signals. Figure 3.4 illustrates the connections between all of the equipment used for the acquisition of the EMG data.

Figure 3.4: Connections between all equipment used in the acquisition of EMG data

In addition to EMG data, musical instrument digital interface (MIDI) data were also collected. A Disklavier[™] Mark III Pro optical sensor system (Yamaha Canada Music Ltd., Toronto, ON), connected to a Yamaha C7 7'6" acoustic grand piano (Yamaha

Canada Music Ltd., Toronto, ON), was used to discern the MIDI data. The optical sensor system was designed to determine the key velocity, note played, and timing (duration a note was held) as the keys were depressed on the acoustic grand piano. In order to synchronize note timing with the EMG data, the Disklavier™ optical sensor system was connected to a MIDI relay (MIDI Solutions Inc., Vancouver, BC) and wired to a NI USB-6008 A/D DAQ device (National Instruments Corporation, Austin, TX). The MIDI relay was programmed to respond to the depression of the G4 key (on the acoustic grand piano); when the G4 key was pressed, the relay would close producing a voltage change measured by the NI USB-6008 A/D DAQ device. Releasing the G4 key would open the relay and return the voltage to the resting position. Delsys® EMGworks 4.1.1 software was used for acquisition of the MIDI relay data. MIDI relay data were collected at a sampling frequency of 1000 Hz, in the ± 5 V range, and at a 12-Bit resolution. Figure 3.5 shows the connections between the equipment used to acquire the MIDI relay data.

Figure 3.5: Connections between equipment used in the acquisition of MIDI relay data

3.4 Experimental Setup

Several criteria were used to select which muscles should be analyzed in the experiment. First, the selected muscles needed to play a key role in the extension and flexion of the wrist and fingers. Second, the EMG signal of the muscles of interest needed to be detectable by surface electrodes. It was also decided that the muscles selected should be in an agonist-antagonist muscle pair, so that co-contraction of the muscles (of the pair) could be investigated (if necessary for this study or future studies). For these reasons, the Extensor Digitorum Communis (EDC), Extensor Carpi Ulnaris (ECU), Flexor Digitorum Superficialis (FDS), and Flexor Carpi Ulnaris (FCU) were the muscles selected for examination. Table 3.1 describes the primary function (action) for each of the selected muscles.^{14, 25, 101} Images showing the anatomical location of these muscles can be found in Figures 2.3 and 2.4.

Muscle	Function/Action
Extensor Digitorum Communis (EDC)	Finger extension
Extensor Carpi Ulnaris (ECU)	Wrist extension and ulnar deviation of the hand
Flexor Digitorum Superficialis (FDS)	Wrist flexion and flexion of the second through fifth fingers
Flexor Carpi Ulnaris (FCU)	Wrist flexion and ulnar deviation of the hand

Table 3.1: Function of the selected muscles

Participants partaking in the study were tested independently. Each participant was seated and the EMG electrodes were placed on the skin above the muscles of their right forearm. The Delsys[®] DE-2.1 sensors (containing two fixed electrodes) were attached to the participants using double-sided adhesive strips. A reference electrode with an integrated gel adhesive pad (Delsys[®] Dermatrod) was placed on the olecranon process of their ulna. The placement location for the electrodes was determined by using SENIAM

guidelines,¹⁰² anatomical markings,^{25, 101} and by having the participants perform muscle isolating movements (for each muscle) with gentle palpation of the desired muscle.²⁵ It was important that the electrodes were placed on the longitudinal midline of each muscle belly so that the quality of the EMG signal was not degraded by cross-talk from other muscles, tendon origins, or innervation zones.^{25, 101} Figures 3.6 and 3.7 show the placement of the electrodes on a participant.

Figure 3.6: Placement of the reference electrode and sensors on the EDC and ECU

Figure 3.7: Placement of sensors on the EDC, FDS and FCU

The EMG sensors and MIDI relay were wired to two different DAQ devices (as shown in Figures 3.4 and 3.5). EMG and MIDI data were acquired and controlled using the Delsys® EMGworks software and timing of the NI USB-6008 and NI USB-6009 DAQ

devices was synchronized by triggering them simultaneously in EMGworks. Table 3.2 outlines the channels selected for each sensor in the Delsys[®] EMGworks software.

Channel	Muscle / Sensor Measured
1	Extensor Digitorum Communis (EDC)
2	Extensor Carpi Ulnaris (ECU)
3	Flexor Digitorum Superficialis (FDS)
4	Flexor Carpi Ulnaris (FCU)
8	MIDI Relay

Table 3.2: Channels selected for each sensor in the Delsys[®] EMGworks software

3.5 Activity Unit Description

There were five activity units in the study that the participants completed. The Pianist Group and the Control Group completed similar exercises in these activity units so that their EMG signals could be accurately compared. The exercises included a Piano Exercise and a Fatiguing Exercise, and these exercises were alternated throughout the course of the study. Table 3.3 shows the order that the exercises were completed in both the Pianist Group and Control Group.

Activity Unit	Pianist Group	Control Group
1	Piano Exercise	Piano Exercise (5 finger pattern only)
2	2 Minute Fatiguing Exercise Session	2 Minute Fatiguing Exercise Session
3	Piano Exercise	Piano Exercise (5 finger pattern only)
4	Fatiguing Exercise Session	Fatiguing Exercise Session
5	Piano Exercise	Piano Exercise (5 finger pattern only)

Table 3.3: Order of exercises completed in the five activity units

In the fourth activity unit, participants were to perform the muscle fatiguing exercise for as long as possible and were told to stop performing the fatiguing exercise when they could no longer maintain the motion or posture instructed. Participants could also elect to stop if they felt they could no longer lift the weight.

3.5.1 Piano Exercise

The piano exercise consisted of repetitions of a five finger pattern (FFP) (which involved no lateral movement of the hand) in 16th notes and was set at a tempo of 60 beats per minute (bpm) where the quarter note gets the beat. In other words, four notes were played every second. The piano exercise for the Pianist Group also incorporated a two octave C Major Scale to make the exercise less monotonous. The Pianist Group repeated the entire piano exercise three times. The Control Group only completed the top line of the piano exercise and this was repeated 15 times. In total, both groups completed approximately 120 seconds of piano playing each time they completed an activity unit containing the piano exercise. A metronome beating at 60 bpm was used to help the participants keep tempo. Figure 3.8 is an image of the piano exercise.

Figure 3.8: Piano Exercise

3.5.2 Fatiguing Exercise

During the muscle fatiguing exercise, participants grasped and lifted a three pound dumbbell. They were told to maintain a posture similar to that used during the piano

exercise; therefore, the arm should be kept relaxed with the elbow flexed at approximately 90 degrees and the palm of their hand facing downward. Participants were instructed to keep the weight parallel to the piano keyboard and to complete the repetitions of lifting the weight upwards with only movement occurring at the wrist. The image of a participant in Figure 3.9 illustrates the posture that was to be maintained during the fatiguing exercise. Figure 3.10 shows the motion of the hand (at the wrist) during the fatiguing exercise.

Figure 3.9: Image of a participant completing the fatiguing exercise

Figure 3.10: Motion of hand during the fatiguing exercise

The fatiguing exercise consisted of two different types of muscular contraction: dynamic (isotonic) and static (isometric- isotonic). During the dynamic contractions, the participants completed 10 repetitions (at a pace of one repetition per second) of lifting the weight upwards by extension of the wrist. This was then followed by a static contraction, where the weight was held upward (with dorsiflexion/extension of the wrist) for 10 seconds. The fatiguing exercise was repeated in this pattern of dynamic/static contractions for two minutes in the second activity unit and for as long as possible in the fourth activity unit. A metronome beating at 60 bpm was used during the fatiguing exercise to help the participants monitor the rate of their contractions.

During both the piano exercise and muscle fatiguing exercise, participants remained seated at the piano. Delsys[®] EMGworks software was used to collect EMG data and MIDI relay data while all of the exercises were being completed.

3.6 Data Segmentation

Following the acquisition of EMG data and MIDI relay data, using Delsys[®] EMGworks software, the raw data files for each participant were exported in .csv format and then imported into MATLAB[®] 7.9.0 (R2009b) (The Mathworks[™], Inc., Natick, MA). A MATLAB[®] algorithm (M-file) was written to plot the raw EMG signal for each channel as well as the MIDI relay data. By analyzing these plots it was possible to determine the section of the EMG signal corresponding to each activity unit. Figure 3.11 (a) shows a plot of the raw EMG signal from all of the muscle channels (from one of the participants), and (b) shows a plot of the MIDI relay data (from one of the participants).

Figure 3.11: Plots of the (a) EMG signal and (b) MIDI data from one participant

As shown by the labels between the plots in Figure 3.11, the five activity units completed by the participants were evident. By zooming in on these plots, it was possible to manually pin point the time that each of the activity units began and ended and these times were recorded in a table for each participant. The following series of images show how the activity units containing the piano exercise were segregated.

Figure 3.12: Piano Exercise marked to indicate when the G4 key was pressed

Figure 3.13: Zoomed in plot of the MIDI data from one participant

As explained in section 3.3, the MIDI relay was programmed to respond to the depression of the G4 key. When the G4 key was pressed, the MIDI relay would close, producing a change in voltage measured by the DAQ device. When the G4 key was released the MIDI relay would open and the voltage would return to the resting position. Figure 3.13 shows the voltage changes measured during the collection of the MIDI relay data.

Manually segregating the EMG signal into the various sections of the piano exercise was simplified for the Pianist Group, by recognizing the repeated pattern in the MIDI data. The plot of the MIDI data for the Control Group was slightly different because it only showed 60 repetitions of the FFP, but it was still easy to manually segregate the EMG signal by recognizing the repeated pattern in the MIDI data.

Activity units containing the fatiguing exercise were also manually segregated by identifying the pattern in the EMG signal. Figure 3.14 shows a segment from a participant's EMG signal corresponding to 10 repetitions of the dynamic contractions (lifting the weight) followed by a static contraction (holding the weight for 10 seconds).

Figure 3.14: Zoomed in plot of the EMG signal from one participant

The repeating pattern of dynamic and static contractions during the fatiguing exercise (shown in the EMG signal in Figure 3.14) was the same for participants of both the Pianist Group and the Control Group.

3.7 Data Processing

A FatigueFinder algorithm (M-file) was written in MATLAB[®] after segregating each participant's EMG signal into segments from each of the five activity units. Running the algorithm produced a plot for each of these segments so that it was possible to visually verify that the EMG signal had been properly segregated. The algorithm also called a function that was written to calculate the power spectral density (PSD), median frequency (MDF), and total power for each segment of the EMG signal. A notch filter was also written into the function to remove 60 Hz noise and the odd harmonics (180 Hz, 300 Hz, and 420 Hz) from the frequency domain of the EMG signal. Each participant's EMG signal segmentation data were recorded in Excel and can be found in Appendix E.

The total power of each EMG signal segment was determined by squaring the values of the EMG signal segment and taking the mean.

$$Power_{Total} = mean(emgseg^2) \quad (3-1)$$

The output voltage of the EMG signal occurred in the time domain; however, the power spectrum of the EMG signal was needed to show how the power was distributed throughout the frequency domain. The Fast Fourier Transform (FFT) was used to convert each EMG signal segment into the frequency domain. The PSD (magnitude of the frequency response) was determined by taking the absolute value of the converted EMG signal segment and then squaring it.

$$P(f) = |FFT_{emgseg}(f)|^2 \quad (3-2)$$

Plotting the PSD amplitudes with respect to frequency generates the PSD curve. The total area underneath the PSD curve is equal to the total power. The calculation of total power in equation 3-1 was completed in the time domain; the total power could have also been calculated in the frequency domain by finding the area underneath the PSD curve.

MDF was calculated for each EMG signal segment by determining the area underneath the PSD curve (using cumulative trapezoidal numerical integration), and finding the frequency (f_{med}) that divides the area underneath the curve into two equal regions. The bandwidth of each EMG signal segment occurred between f_1 and f_2 . The MDF therefore occurred when 50% of the total power was reached and equation 3-3 was true.

$$\int_{f_1}^{f_{med}} P(f)df = \int_{f_{med}}^{f_2} P(f)df \quad (3-3)$$

Figure 3.15 shows the location of the MDF on a typical PSD curve.

Figure 3.15: Typical PSD curve and location of MDF

The results of the MDF and total power calculations were recorded in Excel and analyzed for each participant to determine if muscle fatigue had occurred. Tables with each participant's MDF values can be found in Appendix F and plots of these MDF values in sequence by activity unit for each participant can be found in Appendix G.

3.8 Terminology and Statistical Analysis

There is terminology used throughout this thesis describing various parts of the EMG signal. This terminology is clarified as follows:

- “Segment” refers to an individual segment of the EMG signal (e.g. FFP6).
- “Session” refers to one activity unit (e.g. PE2 is the second piano exercise session).
- “Section” refers to part of the fatiguing exercise where either dynamic (isotonic) or static (isometric/isotonic) contractions were performed (e.g. FE1D is the dynamic section of the first fatiguing exercise session), and includes all of the EMG signal segments performed during that section (e.g. FE1D includes segments FEIT1-FEIT6).

The Exact Goodness of Fit Test and Fisher's Exact Test of Independence were performed in Excel to statistically analyse all of the findings in Chapters 4-6. The following interpretation of confidence levels was used for the statistical analysis:

Confidence Level (%)	P-value	Interpretation
> 90	$P > 0.10$	No evidence against the null hypothesis. Data appears to be consistent with the null hypothesis.
90-92	$0.08 < P < 0.10$	Weak evidence against the null hypothesis in favour of the alternative.
92-95	$0.05 < P < 0.08$	Moderate evidence against the null hypothesis in favour of the alternative.
95-99	$0.01 < P < 0.05$	Strong evidence against the null hypothesis in favour of the alternative.
99-99.9	$0.001 < P < 0.01$	Very strong evidence against the null hypothesis in favour of the alternative.

4 Chapter: Fatiguing Exercise

4.1 Introduction

Two of the five activity units (the second and fourth) completed by the participants consisted of a fatiguing exercise. The purpose of the fatiguing exercise was to determine if the large extrinsic muscles of the forearms were fatigable and to use these results as a basis for comparison when analysing the results from the piano exercise. Both the Pianist Group (11 participants) and Control Group (5 participants) completed the same fatiguing exercise so that their muscle activity (recorded in an EMG signal) could be compared.

4.2 Methodology

The methodology of the fatiguing exercise is detailed in section 3.5.2. The fatiguing exercise consisted of dynamic contractions (where participants completed 10 repetitions of lifting a weight upwards) and static contractions (where participants held a weight upwards for 10 seconds). The fatiguing exercise was repeated in the pattern of dynamic/static contractions for two minutes in the second activity unit and for as long as possible in the fourth activity unit. Participants were verbally encouraged to continue the fatiguing protocol, and the end of the fatiguing exercise was determined when a participant could no longer maintain the motion or posture instructed, or elected to stop.

4.3 Results

The EMG signal obtained during the fatiguing exercise was manually segregated (as explained in section 3.6) to separate the fatiguing exercise into the dynamic contraction

and static contraction sections, and was processed (as explained in section 3.7) to determine the MDF and total power of each EMG signal segment. EMG signal segments of the fatiguing exercise and values of the calculated MDF for each segment can be found in Appendix E and Appendix F, respectively.

The MDF values were plotted for each muscle of each participant for each fatiguing exercise section, and the slope (positive or negative) of the trendline was determined. Figure 4.1 illustrates the trends of the MDF data for static contractions of the first fatiguing exercise (activity unit 2) in the EDC muscle of all participants. Plots of the remaining muscles and of the dynamic contractions for each muscle can be found in Appendix H. A table with the slope direction and correlation coefficient of each participant's MDF values is also included with the plots in Appendix H.

Figure 4.1: Plot of MDFs in Fatiguing Exercise 1 Static Contractions in EDC

Totals of the MDF slope trends for each participant group were compiled in Table 4.1.

		Fatiguing Exercise MDF Trend Results								Slope
		Static				Dynamic				
		FE1S		FE2S		FE1D		FE2D		
		Pianists	Controls	Pianists	Controls	Pianists	Controls	Pianists	Controls	
Muscle	EDC	8	5	10	5	9	5	10	4	Negative
		3	0	1	0	2	0	1	1	Positive
	ECU	7	5	9	5	8	4	8	4	Negative
		3	0	1	0	2	1	2	1	Positive
	FDS	7	4	10	5	10	5	10	5	Negative
		4	1	1	0	1	0	1	0	Positive
	FCU	10	3	9	5	6	4	7	4	Negative
		1	2	2	0	5	1	4	1	Positive

Table 4.1: Fatiguing Exercise MDF Trends for the Pianist Group and Control Group

There were some instances where motion artifacts occurred in the EMG signal.

Segments that were significantly impacted by the motion artifacts, where slope of the MDF trendline, the correlation coefficient, or both of these values were altered, were excluded from the analysis; the EMG segments removed are listed in Table 4.2.

		Motion Artifacts Removed		
		P1031F	C9052F	C9291M
Muscle	EDC			
	ECU			
	FDS			FEIM30, FEIM31
	FCU	FEIM2, FEIT3	FEIT21	FEIM5, FEIM31

Table 4.2: EMG segments removed from the analysis due to motion artifacts

MDF trends for both participant groups were analysed to determine if there was any statistical significance in the results. The sample size of the data was small so, as recommended by McDonald,¹⁰³ the exact goodness-of-fit test and Fisher's exact test of independence were used for the analysis because “Chi-square and *G*-tests of goodness-of-fit or independence give inaccurate results when the expected numbers are small”.

A two-tailed exact goodness-of-fit test was performed in Excel to determine the statistical significance of the MDF trend results. A null hypothesis, that there would not be a significant trend of muscle fatigue, was used and therefore if the null hypothesis was true, the expected MDF trend would show an equal number of positive and negative slopes. The research hypothesis was that muscle fatigue would occur (as shown by a negative slope in the MDF trend - the gold standard for detection of muscle fatigue). P-values related to the number of participants showing a negative MDF trend (for the static and dynamic sections of the fatiguing exercise) are listed in Table 4.3 for (a) all participants, (b) the Pianist Group, and (c) the Control Group.

(a)		Fatiguing Exercise - All Participants			
		Static		Dynamic	
		FE1S	FE2S	FE1D	FE2D
Muscle	EDC	0.0213	0.0005	0.0042	0.0042
	ECU	0.0352	0.0010	0.0352	0.0352
	FDS	0.2101	0.0005	0.0005	0.0005
	FCU	0.0213	0.0042	0.4545	0.2101
(b)		Fatiguing Exercise - Pianist Group			
		Static		Dynamic	
		FE1S	FE2S	FE1D	FE2D
Muscle	EDC	0.2266	0.0117	0.0654	0.0117
	ECU	0.3438	0.0215	0.1094	0.1094
	FDS	0.5488	0.0117	0.0117	0.0117
	FCU	0.0117	0.0654	1.0000	0.5488
(c)		Fatiguing Exercise - Control Group			
		Static		Dynamic	
		FE1S	FE2S	FE1D	FE2D
Muscle	EDC	0.0625	0.0625	0.0625	0.3750
	ECU	0.0625	0.0625	0.3750	0.3750
	FDS	0.3750	0.0625	0.0625	0.0625
	FCU	1.0000	0.0625	0.3750	0.3750

Table 4.3: P-values related to MDF trends during the fatiguing exercise

Cells in Table 4.3 that are highlighted in green, indicate that there is strong evidence to reject the null hypothesis at a confidence level of 96% (or better) in support of the research hypothesis that muscle fatigue is likely to occur during those portions of the fatiguing exercise. Cells highlighted in yellow, show moderate evidence against the null hypothesis in favour of the research hypothesis at about a 93% confidence level. However, the moderate evidence shown in the Control Group was because of the small sample size; if the sample size was larger, greater significance could have been achieved. Cells that have not been highlighted show no evidence against the null hypothesis and appear to be consistent with null hypothesis.

A two-tailed Fisher's exact test of independence was performed in Excel to compare the Pianist Group and Control Group to determine if there were any differences between them with respect to the development of muscle fatigue. The null hypothesis was that muscle fatigue was equally likely to occur in the participants of both groups. Table 4.4 shows the P-values related to whether or not being in one group or the other had an impact on the likelihood of developing muscle fatigue during the fatiguing exercise.

		Fatiguing Exercise			
		Static		Dynamic	
		FE1S	FE2S	FE1D	FE2D
Muscle	EDC	0.5089	1.0000	1.0000	1.0000
	ECU	0.5055	1.0000	1.0000	1.0000
	FDS	1.0000	1.0000	1.0000	1.0000
	FCU	0.2143	1.0000	0.5879	1.0000

Table 4.4: P-values related to group comparison of MDF trends

As shown by the P-values of Table 4.4, there is no evidence against the null hypothesis or evidence that one group is more likely than the other to develop muscle fatigue during any section of the fatiguing exercise.

The total power values for each EMG signal segment of the fatiguing exercise were also calculated. These values were plotted for each muscle of each participant for each fatiguing exercise section, and the slope (positive or negative) of the trendline was determined. Figure 4.2 illustrates the trend of the total power data for static contractions of the first fatiguing exercise (activity unit 2) in the EDC muscle of all participants. Plots of the remaining muscles and of the dynamic contractions for each muscle can be found in Appendix I. A table with the slope direction and correlation coefficient of each participant's total power values is also included with the plots in Appendix I.

Figure 4.2: Plot of Total Power in Fatiguing Exercise 1 Static Contractions in EDC

Total power slope trends for each participant group were compiled in Table 4.5. Note that EMG segments listed in Table 4.2 (that were removed from the MDF analysis due to motion artifacts) were also removed from the total power analysis. As well, all of the total power values were multiplied by a factor of 10^{10} for easier plotting of the results.

		Fatiguing Exercise Total Power Trend Results								Slope
		Static				Dynamic				
		FE1S		FE2S		FE1D		FE2D		
		Pianists	Controls	Pianists	Controls	Pianists	Controls	Pianists	Controls	
Muscle	EDC	6	3	2	3	6	2	3	1	Negative
		5	2	9	2	5	3	8	4	Positive
	ECU	5	2	6	3	6	2	6	1	Negative
		5	3	4	2	4	3	4	4	Positive
	FDS	9	5	8	1	11	4	8	2	Negative
		2	0	3	4	0	1	3	3	Positive
	FCU	10	3	11	3	10	5	8	5	Negative
		1	2	0	2	1	0	3	0	Positive

Table 4.5: Fatiguing Exercise Total Power Trends for the Pianist and Control Groups

Total power trends for both participant groups were analysed to determine if there was any statistical significance in the results. Total power values (which are related to the amplitude of the EMG signal) could support findings of muscle fatigue (as determined by declining MDF values), but are not reliable to use as fatigue index and were not used to determine whether or not muscle fatigue occurred.

A two-tailed exact goodness-of-fit test was performed in Excel to determine the statistical significance of the total power trend results. A null hypothesis, that there would not be a significant increase or decrease in total power trend was used, and if true, the expected total power trend would show an equal number of positive and negative slopes. The research hypothesis was that the total power trend would decline. P-values related to the number of participants showing a positive or negative total power trend (for the static and

dynamic sections of the fatiguing exercise) are listed in Table 4.6 for (a) all participants, (b) the Pianist Group, and (c) the Control Group.

(a)		Fatiguing Exercise - All Participants			
		Static		Dynamic	
		FE1S	FE2S	FE1D	FE2D
Muscle	EDC	0.8036	0.2101	1.1964	0.0768
	ECU	1.0000	0.6072	1.0000	1.0000
	FDS	0.0042	0.8036	0.0005	0.4545
	FCU	0.0213	0.0042	0.0005	0.0213
(b)		Fatiguing Exercise - Pianist Group			
		Static		Dynamic	
		FE1S	FE2S	FE1D	FE2D
Muscle	EDC	1.0000	0.0654	1.0000	0.2266
	ECU	1.2461	0.7539	0.7539	0.7539
	FDS	0.0654	0.2266	0.0010	0.2266
	FCU	0.0117	0.0010	0.0117	0.2266
(c)		Fatiguing Exercise - Control Group			
		Static		Dynamic	
		FE1S	FE2S	FE1D	FE2D
Muscle	EDC	1.0000	1.0000	1.0000	0.3750
	ECU	1.0000	1.0000	1.0000	0.3750
	FDS	0.0625	0.3750	0.3750	1.0000
	FCU	1.0000	1.0000	0.0625	0.0625

Table 4.6: P-values related to total power trends during the fatiguing exercise

Cells in Table 4.6 that are highlighted in green, indicate that there is strong evidence to reject the null hypothesis at a confidence level of 97% (or better) in support of the research hypothesis that the total power trend would likely decline (possibly due to the presence of muscle fatigue). Cells highlighted in yellow show moderate evidence against the null hypothesis in favour of the research hypothesis at about a 93% confidence level. However, the moderate evidence shown in the Control Group was because of the small sample size; if the sample size was larger, greater significance could have been achieved.

Cells highlighted in purple, show moderate evidence (at about a 92% confidence level) against the null hypothesis, but indicate that there would likely be an increasing total power trend (in the EDC muscle of all participants during the dynamic contraction section of the second fatiguing exercise (FE2D) and in the EDC muscle of the pianists during the static contraction section of the second fatiguing exercise (FE2S)); this will be explained in the discussion section. Cells that have not been highlighted show no evidence against the null hypothesis and appear to be consistent with null hypothesis.

A two-tailed Fisher's exact test of independence was performed in Excel to compare the Pianist Group and Control Group to determine if there were any differences between them with respect to total power trends. The null hypothesis was that the total power trend was equally likely to increase or decrease in both groups of participants. Table 4.7 shows the P-values related to whether or not being in one group or the other had an impact on the slope of the total power trend.

		Fatiguing Exercise			
		Static		Dynamic	
		FE1S	FE2S	FE1D	FE2D
Muscle	EDC	1.0000	0.2445	1.0000	1.0000
	ECU	1.0000	1.0000	0.6084	0.2821
	FDS	1.0000	0.1058	0.3125	0.2995
	FCU	0.2143	0.0833	1.0000	0.5089

Table 4.7: P-values related to group comparison of total power trends

As shown by the P-values of Table 4.7, for the most part, there is no evidence against the null hypothesis that one group is more likely than the other to show a trend of total power increase or decline. However, weak evidence (at about a 91% confidence level) was shown that being a pianist does impact the likelihood of having a declining total power

trend in the FCU muscle during the static contraction section of the second fatiguing exercise (FE2S).

4.4 Discussion

An important aspect of the experimental methodology was to determine that muscle fatigue could be detected in the muscles being analysed. Thus, the fatiguing exercise was designed to cause muscle fatigue using known muscle fatiguing protocols: collection of EMG data during sustained short-duration isometric-isotonic contractions and/or controlled cyclic dynamic contractions, and then identifying the downward shift in the power spectrum using MDF (or MNF) as a fatigue index to identify the frequency shift.

Due to the nature of the types of exercises being performed, there were some instances where motion artifacts in the EMG signal were created; these were visible as large spikes (amplitudes) in the EMG signal relative to the typical signal amplitude of the muscle being measured. EMG segments that were significantly impacted by the motion artifacts were excluded from the analysis of the fatiguing exercise.

The fatiguing exercise was made as dynamically equivalent as possible across the participants (by having them move in time with a metronome), but despite this there were still differences in the duration of the fatiguing exercise, where some of the participants had elected to stop and others were told to stop because they could no longer maintain the position of their hand/arm. It was not possible to determine if all of the participants attained the same level of muscle fatigue during the fatiguing exercise, but observation of

their performance indicated that some degree of muscle fatigue had likely been reached. One reason the participants elected to stop could have been related to the redundancy of the task, causing the participants to experience mental fatigue as well as physical fatigue. Alternatively, the participants could have used different muscle activation patterns to maintain the task performance (without obvious changes in movement variability) or could possess different muscle fatigue thresholds, which (depending on the participant's motivation) would determine if they were able to push through the early stages of fatigue (which can be uncomfortable). Responses to questions collected from the Pianist Group (in Appendix C) provide some insight as to why the participants elected to stop (or were told to stop). The responses support the theory that they used different muscle activation patterns to perform the fatiguing exercise, based on where the participants felt their muscles fatigue.

Plots of the MDF values (for each muscle of each participant for both the static and dynamic contraction sections of the fatiguing exercise) were useful for visualizing consistencies and differences in the MDF trends. Statistical analysis of the MDF trend results showed strong evidence ($P < 0.04$) in support of the research hypothesis that muscle fatigue (as shown by decreasing MDF values) was likely to occur during the all sections of the fatiguing exercise. The only exceptions to this result were that the FCU muscle (during the dynamic sections of the first and second fatiguing exercise (FE1D and FE2D)) and the FDS muscle (during the static section of the first fatiguing exercise (FE1S)) did not show any evidence against the null hypothesis and were therefore unlikely to experience muscle fatigue during those sections of the fatiguing exercise.

Comparison of the Pianist Group to the Control Group (to determine if there were any differences between them with respect to the development of muscle fatigue), showed no evidence against the null hypothesis and muscle fatigue was therefore equally likely to occur in both groups of participants. Thus, being in one group or the other had no impact on the likelihood of developing muscle fatigue during the fatiguing exercise.

Similar to the MDF values, plots of the total power values (for each muscle of each participant for both the static and dynamic contraction sections of the fatiguing exercise) were useful for visualizing consistencies and differences in the total power trends.

Statistical analysis of the total power trends showed strong evidence ($P < 0.03$) that the total power is likely to decrease in the flexor muscles (especially the FCU) of all participants during both sections of the fatiguing exercise. This result was expected due to the slowdown of muscle fiber conduction velocity and the loss of muscular excitability typical of muscle fatigue. Conversely, moderate evidence ($P < 0.07$) was shown for an increasing total power trend in the EDC muscle of the pianists during the static contraction section of the second fatiguing exercise (FE2S), and for the EDC muscle of all participants ($P < 0.08$) during the dynamic contraction section of the second fatiguing exercise (FE2D). Fatigue-induced increase in power of the EMG spectrum is thought to occur with the recruitment of supplementary motor units and/or increased motor unit firing rates. Several factors may be attributed to inconsistency of the total power trends: 1) variability of the active motor unit pool, 2) recruitment–derecruitment of motor units with variable firing rates, 3) sharing of the load among synergistic muscles, and 4) effects of central and peripheral fatigue.

Comparison of the Pianist Group to the Control Group (to determine if there were any differences between them with respect to total power trends) showed, for the most part, no evidence against the null hypothesis and therefore neither group was more likely than the other to show a trend of total power increase or decline during the fatiguing exercise. However, weak evidence ($P < 0.09$) was shown that being a pianist does impact the likelihood of having a declining total power trend in the FCU muscle during the static contraction section of the second fatiguing exercise (FE2S). Several hypotheses can explain this result: 1) muscle fatigue may induce a reduction in activation level of the forearm muscles, which would be shown by the declining total power, and 2) conscious or subconscious strategies of the CNS could lead to a redistribution of muscle activity to non-fatigued muscles in order to protect the fatigued muscles and/or limit performance losses. Future investigation is warranted to determine greater significance of this finding.

4.5 Conclusion

It was determined with significant evidence ($P < 0.04$) that muscle fatigue is likely to occur (especially in the extensor muscles) during the fatiguing exercise, which meets part of the first thesis objective by showing that muscle fatigue is detectable in the forearm muscles. This finding was expected in the extensor muscles due to the nature of the movement during the fatiguing exercise, but the significant results of muscle fatigue in the flexor muscles was surprising. The results verify that the fatigue tracking method (using MDF as a fatigue index to identify the downward shift in the power spectrum) is effective, and also provide a useful basis of comparison because of other researcher's evidence that piano playing places a large amount of stress on the extensor muscles.

There was no evidence that muscle fatigue is more likely to develop in one participant group or the other during the fatiguing exercise, but weak evidence ($P < 0.09$) was shown that pianists are more likely to have a declining total power trend in the FCU muscle during the static contraction section of the second fatiguing exercise (FE2S). This decline in total power may be related to decreased muscle activity caused by muscle fatigue, but may also be due to strategies of the CNS to redistribute the task load to protect fatigued muscles and/or limit performance losses.

5 Chapter: Piano Exercise

5.1 Introduction

Three of the five activity units (the first, third and fifth) completed by the participants consisted of a piano exercise. The piano exercise was designed to be similar to an exercise a pianist might use to warm-up in a practice session, but also included FFP segments, where there was not any lateral movement of the hand, allowing for better detection of the EMG signals. It is the FFP segments, completed by the Pianist Group (11 participants) and Control Group (5 participants), that were compared in the analysis.

5.2 Methodology

The methodology of the piano exercise is detailed in section 3.5.1. The piano exercise consisted of repetitions of a FFP, and for the Pianist Group a two octave C Major Scale was also incorporated into the piano exercise to make it less monotonous. For each activity unit, the Pianist Group repeated the entire piano exercise three times and the Control Group repeated the top line of the piano exercise 15 times. In total, both groups completed approximately 120 seconds of piano playing each time they completed an activity unit containing the piano exercise.

5.3 Results

The EMG signal obtained during the piano exercise was manually segregated (as explained in section 3.6) to differentiate the FFP segments (and scale sections) and was processed (as explained in section 3.7) to determine the MDF and total power of each

FFP EMG signal segment. EMG signal segments and values of the calculated MDF for each FFP segment can be found in Appendix E and Appendix F, respectively.

The MDF values were plotted for each muscle of each participant for the piano exercise, and the slope (positive or negative) of the trendline was determined. Figure 5.1 illustrates the trends of the MDF data for the first piano exercise (activity unit 1) in the EDC muscle of all participants. Plots of the remaining muscles and piano exercise sessions can be found in Appendix J. A table with the slope direction and correlation coefficient of each participant's MDF values is also included with the plots in Appendix J.

Figure 5.1: Plot of MDFs in Piano Exercise 1 in EDC

MDF trends for both participant groups were analysed to determine if there was any statistical significance in the results. Totals of the MDF slope trends for each participant group were compiled in Table 5.1.

		Piano Exercise MDF Trend Results						
		PE1		PE2		PE3		
		Pianists	Controls	Pianists	Controls	Pianists	Controls	
Muscle	EDC	4	4	1	1	1	1	Negative
		7	1	10	4	10	4	Positive
	ECU	8	5	1	1	1	0	Negative
		2	0	9	4	9	5	Positive
	FDS	6	5	2	5	3	4	Negative
		5	0	9	0	8	1	Positive
	FCU	6	2	3	5	6	4	Negative
		5	3	8	0	5	1	Positive

Table 5.1: Piano Exercise MDF Trends for the Pianist Group and Control Group

There were some instances where motion artifacts occurred in the EMG signal.

Segments that were significantly impacted by the motion artifacts, where slope of the MDF trendline, the correlation coefficient, or both of these values were altered, were excluded from the analysis; the EMG segments removed are listed in Table 5.2.

		Motion Artifacts Removed	
		C9052F	C10102F
Muscle	EDC	FFP42, FFP44, FFP45	
	ECU		
	FDS	FFP32, FFP35	FFP7, FFP8
	FCU	FFP21	FFP11, FFP15, FFP21

Table 5.2: EMG segments removed from the analysis due to motion artifacts

A two-tailed exact goodness-of-fit test was performed in Excel to determine the statistical significance of the MDF trend results. A null hypothesis that there would not be a significant trend of muscle fatigue was used, and if the null hypothesis was true, the expected MDF trend would show an equal number of positive and negative slopes. The research hypothesis was that muscle fatigue (or recovery) would occur (as shown by a negative (or positive) slope in the MDF trend). P-values related to the number of

participants showing a negative (or positive) MDF trend for the piano exercise are listed in Table 5.3 for (a) all participants, (b) the Pianist Group, and (c) the Control Group.

(a)		Piano Exercise - All Participants		
		PE1	PE2	PE3
Muscle	EDC	1.1964	0.0042	0.0042
	ECU	0.0074	0.0074	0.0010
	FDS	0.2101	0.8036	0.8036
	FCU	1.1964	1.1964	0.4545
(b)		Piano Exercise - Pianist Group		
		PE1	PE2	PE3
Muscle	EDC	0.5488	0.0117	0.0117
	ECU	0.1094	0.0215	0.0215
	FDS	1.0000	0.0654	0.2266
	FCU	1.0000	0.2266	1.0000
(c)		Piano Exercise - Control Group		
		PE1	PE2	PE3
Muscle	EDC	0.3750	0.3750	0.3750
	ECU	0.0625	0.3750	0.0625
	FDS	0.0625	0.0625	0.3750
	FCU	1.0000	0.0625	0.3750

Table 5.3: P-values related to MDF trends during the piano exercise

The cell highlighted in green in Table 5.3, indicates that there is strong evidence to reject the null hypothesis at a confidence level of 99% in support of the research hypothesis that muscle fatigue is likely to occur during that piano exercise session. Cells highlighted in blue, indicate that there is strong evidence to reject the null hypothesis at a confidence level of 97% (or better) in support of the research hypothesis that muscle recovery is likely to occur during those sessions of the piano exercise. Cells highlighted in yellow, show moderate evidence (at about a 93% confidence level) against the null hypothesis in favour of the research hypothesis that the MDF trend would likely decline. Cells highlighted in purple, show moderate evidence (at about a 93% confidence level) against

the null hypothesis in favour of the research hypothesis that the MDF trend would likely increase (showing muscle recovery). However, the moderate evidence shown in the Control Group was because of the small sample size; if the sample size was larger, greater significance could have been achieved. Cells that have not been highlighted show no evidence against the null hypothesis and appear to be consistent with the null hypothesis.

A two-tailed Fisher's exact test of independence was performed in Excel to compare the Pianist Group and Control Group to determine if there were any differences between them with respect to the development of muscle fatigue (or recovery). The null hypothesis was that muscle fatigue (or recovery) was equally likely to occur in the participants of both groups. Table 5.4 shows the P-values related to whether or not being in one group or the other had an impact on the likelihood of developing muscle fatigue (or recovery) during the piano exercise.

		Piano Exercise		
		PE1	PE2	PE3
Muscle	EDC	0.2821	1.0000	1.0000
	ECU	0.5238	1.0000	1.0000
	FDS	0.1186	0.0048	0.1058
	FCU	1.0000	0.0256	0.5879

Table 5.4: P-values related to group comparison of MDF trends

As shown by the P-values of Table 5.4, for the most part, there is no evidence against the null hypothesis that one group is more likely than the other show a trend of muscle fatigue (or recovery) in the extensor muscles during the piano exercise. However, strong evidence (at a confidence level of 97% (or better)) was shown that being a pianist may

prevent the likelihood of developing muscle fatigue in the flexor muscles (FDS and FCU) during the second piano exercise (PE2). All of the participants of the Control Group exhibited muscle fatigue during this piano exercise session, whereas the majority of participants in the Pianist Group showed muscle recovery.

The total power values for each FFP EMG signal segment of the piano exercise were also calculated. These values were plotted for each muscle of each participant for the piano exercise, and the slope (positive or negative) of the trendline was determined. Figure 5.2 illustrates the trends of the total power data for the first piano exercise (activity unit 1) in the EDC muscle of all participants. Plots of the remaining muscles and piano exercise sessions can be found in Appendix K. A table with the slope direction and correlation coefficient of each participant's total power values is also included in Appendix K.

Figure 5.2: Plot of Total Power in Piano Exercise 1 in EDC

Total power slope trends for each participant group were compiled in Table 5.5. Note that EMG segments listed in Table 5.2 (that were removed from the MDF analysis due to motion artifacts) were also removed from the total power analysis. As well, the total power values were all multiplied by a factor of 10^{10} for easier plotting of the results.

		Piano Exercise MDF Trend Results						
		PE1		PE2		PE3		
		Pianists	Controls	Pianists	Controls	Pianists	Controls	
Muscle	EDC	10	3	8	2	9	3	Negative
		1	2	3	3	2	2	Positive
	ECU	7	2	3	2	6	3	Negative
		3	3	7	3	4	2	Positive
	FDS	5	4	6	0	7	0	Negative
		6	1	5	5	4	5	Positive
	FCU	8	3	6	0	5	1	Negative
		3	2	5	5	6	4	Positive

Table 5.5: Piano Exercise Total Power Trends for the Pianist and Control Groups

Total power trends for both participant groups were analysed to determine if there was any statistical significance in the results. Total power values (which are related to the amplitude of the EMG signal) could support findings of muscle fatigue (as determined by declining MDF values), but are not reliable to use as fatigue index and were not used to determine whether or not muscle fatigue occurred.

A two-tailed exact goodness-of-fit test was performed in Excel to determine the statistical significance of the total power trend results. A null hypothesis, that there would not be a significant increase or decrease in total power trend was used, and if true, the expected total power trend would show an equal number of positive and negative slopes. The research hypothesis was that the total power trend would decline. P-values related to the number of participants showing a positive or negative slope of the total power trend in

the piano exercise are listed in Table 5.6 for (a) all participants, (b) the Pianist Group, and (c) the Control Group.

(a)		Piano Exercise - All Participants		
		PE1	PE2	PE3
Muscle	EDC	0.0213	0.4545	0.0768
	ECU	0.6072	0.3018	0.6072
	FDS	0.8036	0.4545	0.8036
	FCU	0.2101	0.4545	0.4545
(b)		Piano Exercise - Pianist Group		
		PE1	PE2	PE3
Muscle	EDC	0.0117	0.2266	0.0654
	ECU	0.3438	0.3438	0.7539
	FDS	1.0000	1.0000	0.5488
	FCU	0.2266	1.0000	1.0000
(c)		Piano Exercise - Control Group		
		PE1	PE2	PE3
Muscle	EDC	1.0000	1.0000	1.0000
	ECU	1.0000	1.0000	1.0000
	FDS	0.3750	0.0625	0.0625
	FCU	1.0000	0.0625	0.3750

Table 5.6: P-values related to total power trends during the piano exercise

Cells in Table 5.6 that are highlighted in green, indicate that there is strong evidence to reject the null hypothesis at a confidence level of 97% (or better) in support of the research hypothesis that the total power trend would likely decline (possibly due to the presence of muscle fatigue). Cells highlighted in yellow, also show moderate evidence (at about a 92% confidence level) against the null hypothesis in favour of the research hypothesis that the total power trend would likely decline. Cells highlighted in purple, show moderate evidence (at about a 93% confidence level) against the null hypothesis, but indicate that the total power trend would likely increase; this will be explained in the discussion section. Note that the moderate evidence shown in the Control Group was

because of the small sample size; if the sample size was larger, greater significance could have been achieved. Cells that have not been highlighted show no evidence against the null hypothesis and appear to be consistent with null hypothesis.

A two-tailed Fisher's exact test of independence was performed in Excel to compare the Pianist Group and Control Group to determine if there were any differences between them with respect to total power trends. The null hypothesis was that the total power trend was equally likely to increase or decrease in both groups of participants. Table 5.7 shows the P-values related to whether or not being in one group or the other had an impact on the slope of the total power trend.

		Piano Exercise		
		PE1	PE2	PE3
Muscle	EDC	0.2143	0.2995	0.5467
	ECU	0.3287	1.0000	1.0000
	FDS	0.3077	0.0934	0.0337
	FCU	1.0000	0.0934	0.5879

Table 5.7: P-values related to group comparison of total power trends

As shown by the P-values of Table 5.7, for the most part, there is no evidence against the null hypothesis that one group is more likely than the other to show a trend of total power increase or decline in the extensor muscles during the piano exercise. However, strong evidence (at a 96% confidence level) was shown that the Control Group is more likely to have an increasing total power trend in the FDS muscle during the third piano exercise session (PE3), and weak evidence (at a 90% confidence level) that the Control Group is more likely to have an increasing total power trend in the FDS and FCU muscles during the second piano exercise session (PE2).

5.4 Discussion

EMG signals recorded during the piano exercise were essential for examining the activity of the forearm muscles during piano playing. It was important to design the piano exercise in such a way that the Control Group of non-pianists could complete it, yet make it similar enough to the task of the Pianist Group so that the results could be compared.

The piano exercise designed was similar to an exercise a pianist might use to warm-up during a practice session, but also included FFP segments, where there was not any lateral movement of the hand, allowing for better detection of the EMG signals. Previous studies,⁷ have used similar strategies of minimizing the medio-lateral and pronation-supination movements of the hand and arm while investigating upper extremity activity during piano playing. However, despite the restriction of lateral movement during the FFP sections of the piano exercise, there were still some instances where motion artifacts in the EMG signal were created (visible as large amplitude spikes in the EMG signal relative to the typical signal amplitude of the muscle being measured). EMG segments that were significantly impacted by the motion artifacts were excluded from the analysis of the piano exercise.

Plots of the MDF values (for each muscle of each participant during the piano exercise) were useful for visualizing consistencies and differences in the MDF trends. Statistical analysis of the MDF trend results showed strong evidence ($P < 0.01$) in support of the research hypothesis that muscle fatigue (as shown by decreasing MDF values) is likely to occur in the ECU muscle of all participants during the first piano exercise session (PE1),

and strong evidence ($P < 0.03$) that muscle recovery (as shown by increasing MDF values) is likely to occur in the extensor muscles (EDC and ECU) of the pianists during the second and third piano exercise sessions (PE2 and PE3). It is expected that years of piano training would create metabolic adaptations in the muscles including differences in muscle fiber composition and changes to the CNS' motor control strategy. The results show that the Pianist Group was more resistant to fatigue accumulation (in the extensor muscles) than the Control Group during the piano exercise sessions that followed the fatiguing exercises, and had better ability to recover from fatigue. It is also possible that the C Major Scale sections in the piano exercise (completed by the pianists), provided a confounding factor to this result; the pianists may have used different muscles to perform the scales allowing the muscles being measured to rest.

Moderate evidence ($P < 0.07$) was shown that muscle fatigue is likely to occur in participants in the Control Group in the ECU and FDS muscles during the first piano exercise session (PE1) and in the FDS and FCU muscles in the second piano exercise session (PE2). As well, moderate evidence ($P < 0.07$) was shown that muscle recovery is likely to occur in the ECU muscle of the Control Group during the third piano exercise session (PE3) and in the FDS muscle of the Pianist Group during the second piano exercise session (PE2). However, as noted in the results section, the moderate evidence shown by the Control Group was because of the small sample size; if the sample size was larger, greater significance could have been achieved.

It was anticipated that the Control Group would show muscle fatigue during the piano exercise sessions due to the lack of specific muscle training, and moderate evidence supports that hypothesis. It is also possible that mental fatigue impacted the development of their muscle fatigue as they may have required more concentration than the pianists to complete the piano playing task. It is interesting that the Control Group showed muscle recovery in the ECU muscle during the third piano exercise session (PE3), despite evidence of muscle fatigue in a prior piano exercise session. It is suspected that by the third piano exercise session (PE3), the participants of the Control Group were able to develop a motor control strategy to avoid the development of muscle fatigue, but with such a small sample size, greater evidence would be needed to verify this.

Comparison of the Pianist Group to the Control Group (to determine if there were any differences between them with respect to the development of muscle fatigue), showed for the most part, no evidence against the null hypothesis that one group is more likely than the other to show a trend of muscle fatigue (or recovery) in the extensor muscles during the piano exercise. However, strong evidence ($P < 0.03$) was shown that being a pianist prevents the likelihood of developing muscle fatigue in the flexor muscles (FDS and FCU) during the second piano exercise (PE2). All of the participants of the Control Group exhibited muscle fatigue in the flexor muscles during that piano exercise session, whereas the majority of participants in the Pianist Group showed muscle recovery. This finding provides further evidence of the physiologic changes that can occur to the muscles through years of piano training.

Similar to the MDF values, plots of the total power values (for each muscle of each participant during the piano exercise) were useful for visualizing consistencies and differences in the total power trends. Statistical analysis of the total power trends showed strong evidence ($P < 0.02$) that the total power trend would likely decline in the EDC muscle of the pianists during the first piano exercise session (PE1) and moderate evidence ($P < 0.07$) of the same result in the third piano exercise session (PE3). This result would be expected if muscle fatigue had occurred due to the slowdown of muscle fiber conduction velocity and loss of muscular excitability; however, there was strong evidence ($P < 0.02$) of muscle recovery in the EDC muscle during the third piano exercise session (PE3) in the analysis of the MDF trend. The decreasing total power trend could therefore be related to a reduction in the number of active motor units being used to complete the task because of efficiencies developed during piano training (such as having higher motor unit firing rates and thus requiring less motor units, and load sharing among synergistic muscles).

Participants in the Control Group showed the opposite result. They showed moderate evidence ($P < 0.07$) that the total power trend would likely increase in the flexor muscles (FDS and FCU) during the second piano exercise session (PE2), despite showing moderate evidence of muscle fatigue based on the MDF trends. Therefore, this fatigue-induced increase in the total power trend was likely the result of needing additional motor units and increasing motor unit firing rates to maintain the task performance.

Comparison of the Pianist Group to the Control Group (to determine if there were any differences between them with respect to total power trends) showed, for the most part, no evidence against the null hypothesis and therefore neither group was more likely than the other to show a trend of total power increase or decline in the extensor muscles during the piano exercise. However, strong evidence ($P < 0.04$) was shown that the Control Group was more likely to have an increasing total power trend in the FDS muscle during the third piano exercise session (PE3), and weak evidence ($P < 0.095$) that the Control Group was more likely to have an increasing total power trend in the FDS and FCU muscles during the second piano exercise session (PE2). These increasing total power trends are despite showing moderate evidence of muscle fatigue (based on the MDF trends) in the same piano exercise sessions. This evidence further demonstrates that the deconditioned (untrained) muscles of non-pianists require a higher level of muscle activity while performing the same activity as pianists with trained muscles.

5.5 Conclusion

It was determined with significant evidence ($P < 0.01$) that muscle fatigue is likely to occur in the ECU muscle during the first piano exercise session (PE1) of all participants, which confirms that the first thesis objective (to determine if muscle fatigue is detectable in the forearm muscles used for piano playing) was met. There was also strong evidence ($P < 0.03$) that muscle recovery is likely to occur in the extensor muscles (EDC and ECU) of the pianists during the second and third piano exercise sessions (PE2 and PE3). This finding is important for pianists because it illustrates that they have better ability to

recover from fatigue than non-pianists, and possible prevention of fatigue accumulation (in the extensor muscles) as a result of their piano training.

There was strong evidence ($P < 0.02$) that the total power trend would decline in the EDC muscle of the pianists in the first piano exercise session (PE1), and moderate evidence ($P < 0.07$) of the same result in the third piano exercise session (PE3). The contradiction of declining power despite the muscle showing muscle recovery was assumed to be related to efficiencies developed during piano training requiring less energy expenditure.

When comparing the Pianist Group and the Control Group, significant ($P < 0.03$) differences were found in the flexor muscles (FDS and FCU) during the second piano exercise (PE2). The Control Group exhibited muscle fatigue, whereas the majority of participants in the Pianist Group showed muscle recovery. Additionally, weak evidence ($P < 0.095$) showed that the Control Group was more likely to have an increasing total power trend in the FDS and FCU muscles during the second piano exercise (PE2), supporting the hypothesis that untrained muscles need to recruit additional motor units and/or increase motor unit firing rates in order to maintain the task performance when the muscles are fatigued.

6 Chapter: Comparison Across Activity Units

6.1 Introduction

There were five activity units completed by the participants (as described in section 3.5). In Chapter 4 (Fatiguing Exercise) and Chapter 5 (Piano Exercise), the EMG signals from each activity unit were analysed separately, to determine if there was any development of muscle fatigue, and if specific muscles were impacted by the development of muscle fatigue. However, it was also necessary to determine if there was any cumulative fatigue, carried over from one activity unit to the next, or throughout all five activity units. Comparison across all of the activity units is performed in this chapter.

6.2 Methodology

Sections 3.6 and 3.7 explain how the EMG signal segments for all five activity units were obtained, and how the MDF values for each segment were calculated; these values can be found in Appendix E and Appendix F, respectively. Plots of the MDF values (including the corresponding trendlines) in sequence by activity unit (for each muscle of each participant) can be found in Appendix G. These plots were useful for visualizing the MDF trend across all five activity units, and the quantitative analysis of these trends is compiled in the following results.

6.3 Results

As described in Chapter 4, the results of the MDF values were plotted for each muscle of each participant for each fatiguing exercise section (static and dynamic contractions), and

the slope of the trendline was determined. The tables (in Appendix H) containing the slope direction for each participant were compiled for each fatiguing exercise section across both fatiguing exercise sessions, and then all sections were compiled to determine any instances of cumulative muscle fatigue. Table 6.1 shows the results tabulated.

		Fatiguing Exercise MDF Trend Results						
		Static (FE1S & FE2S)		Dynamic (FE1D & FE2D)		All FE Sections		
		Pianists	Controls	Pianists	Controls	Pianists	Controls	
Muscle	EDC	8	5	9	4	8	4	Same
		3	0	2	1	3	1	Mixed
	ECU	7	5	7	4	7	4	Same
		3	0	3	1	3	1	Mixed
	FDS	7	3	9	5	7	3	Same
		4	2	2	0	4	2	Mixed
	FCU	9	3	6	3	6	2	Same
		2	2	5	2	5	3	Mixed

Table 6.1: Fatiguing Exercise MDF Trends for the Pianist Group and Control Group

Participants that showed the same trend across both static fatiguing exercise sections, both dynamic fatiguing exercise sections, and across both fatiguing exercise activity units were tabulated as “same”, whereas participants that did not show a consistent trend were tabulated as “mixed”. There was evidence that there was a continuous trend across the fatiguing exercise activity units and statistical analysis of the results was performed.

A two-tailed exact goodness-of-fit test was performed in Excel to determine the statistical significance of the cumulative MDF trend results. A null hypothesis, that there would not be a significant trend of cumulative muscle fatigue, was used and therefore if the null hypothesis was true, the expected MDF trend would show an equal number of positive and negative (mixed) slopes. The research hypothesis was that muscle fatigue would occur (as shown by a consistent negative slope in the MDF trend). P-values related to the

number of participants showing a negative cumulative MDF trend are listed in Table 6.2 for (a) all participants, (b) the Pianist Group, and (c) the Control Group.

(a)		Fatiguing Exercise Section - All Participants		
		Static	Dynamic	All
Muscle	EDC	0.0213	0.0213	0.0768
	ECU	0.0352	0.1185	0.1185
	FDS	0.4545	0.0042	0.4545
	FCU	0.0768	0.8036	1.1964
(b)		Fatiguing Exercise Section - Pianist Group		
		Static	Dynamic	All
Muscle	EDC	0.2266	0.0654	0.2266
	ECU	0.3438	0.3438	0.3438
	FDS	0.5488	0.0654	0.5488
	FCU	0.0654	1.0000	1.0000
(c)		Fatiguing Exercise Section - Control Group		
		Static	Dynamic	All
Muscle	EDC	0.0625	0.3750	0.3750
	ECU	0.0625	0.3750	0.3750
	FDS	1.0000	0.0625	1.0000
	FCU	1.0000	1.0000	1.0000

Table 6.2: P-values related to cumulative MDF trends during the fatiguing exercise

Cells in Table 6.2 that are highlighted in green, indicate that there is strong evidence to reject the null hypothesis at a confidence level of 96% (or better) in support of the research hypothesis that there would be cumulative muscle fatigue across both fatiguing exercise activity units. Cells highlighted in yellow, show moderate evidence against the null hypothesis in favour of the research hypothesis at about a 92% confidence level. However, the moderate evidence shown in the Control Group was because of the small sample size; if the sample size was larger, greater significance could have been achieved. Cells that have not been highlighted show no evidence against the null hypothesis and

appear to be consistent with null hypothesis that participants would not show a consistent MDF trend across fatiguing exercise activity units.

A two-tailed Fisher's exact test of independence was performed in Excel to compare the Pianist Group and Control Group to determine if there were any differences between them with respect to cumulative muscle fatigue. The null hypothesis was that cumulative muscle fatigue was equally likely to occur in the participants of both groups. Table 6.3 shows the P-values related to whether or not being in one group or the other had an impact on the likelihood of developing cumulative muscle fatigue across the fatiguing exercise activity units.

		Fatiguing Exercise Section		
		Static	Dynamic	All
Muscle	EDC	0.5089	1.0000	1.0000
	ECU	0.5055	1.0000	1.0000
	FDS	1.0000	1.0000	1.0000
	FCU	0.5467	1.0000	1.0000

Table 6.3: P-values related to group comparison of MDF trends

As shown by the P-values of Table 6.3, there is no evidence against the null hypothesis or evidence that one group is more likely than the other to develop muscle fatigue across the fatiguing exercise activity units.

As described in Chapter 5, the results of the MDF values were plotted for each muscle of each participant for the piano exercise, and the slope of the trendline was determined.

The tables (in Appendix J) containing the slope direction for each participant were

compiled for all of the piano exercise sessions to determine any instances of cumulative fatigue. Table 6.4 shows the results tabulated.

		Piano Exercise MDF Trend Results		
		All PE Sessions		
		Pianists	Controls	
Muscle	EDC	7	2	Same
		4	3	Mixed
	ECU	1	0	Same
		9	5	Mixed
	FDS	7	4	Same
		4	1	Mixed
	FCU	2	2	Same
		9	3	Mixed

Table 6.4: Piano Exercise MDF Trends for the Pianist Group and Control Group

Participants that showed the same trend across all of the piano exercise sessions were tabulated as “same”, whereas participants that did not show a consistent trend were tabulated as “mixed”. The results counted as “same” showed consistent trends of muscle fatigue or muscle recovery across all of the piano exercise sessions.

There were not any statistically significant results determined from the analysis of the MDF trends across the piano exercise activity units. However, it was shown that 4 of 5 participants in the Control Group developed muscle fatigue across all of the piano exercise sessions in the FDS muscle, and 7 of 11 participants in the Pianist Group showed muscle recovery in the EDC muscle across all of the piano exercise sessions.

The change in MDF value was also analysed for the transition from one activity unit to the next. Plots showing the MDF trend across all five activity units (for each muscle of each participant) can be found in Appendix G. Tables 6.5 to 6.8 show trends from these

transitions with positive differences between activity units (potentially indicating fatigue accumulation) highlighted in red. Figure 6.1 also shows (red arrow) an example of a transition with residual fatigue in the ECU, FDS and FCU muscles of one participant.

Figure 6.1: Example of residual fatigue in one participant

Pianist Group											
EDC	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F
Δ PE1-FE1	-0.4254	-7.4761	-2.8836	1.9044	-0.2152	-16.2315	4.0739	3.3205	-0.7302	9.3411	33.6111
Δ FE1-PE2	5.7753	-9.2764	-12.0913	10.8674	21.3482	27.9716	12.0967	11.2252	6.1426	4.4332	-36.9236
Δ PE2-FE2	-4.7861	-1.4822	-14.2537	-8.8223	-12.9178	-40.0217	-1.4586	-10.0612	3.3467	12.1406	36.9235
Δ FE2-PE3	2.7828	-0.3799	10.2759	4.0294	23.3038	35.9824	13.0969	8.9910	-1.6126	-7.0333	-34.7616

Control Group					
EDC	P9052F	C9231F	C9291M	C10101F	C10102F
Δ PE1-FE1	-16.7200	21.1288	-9.2916	21.2345	-1.8910
Δ FE1-PE2	8.0248	-27.2514	-0.5956	-13.4235	-0.1732
Δ PE2-FE2	-2.6074	17.6087	-8.8148	26.1771	1.3631
Δ FE2-PE3	-1.7921	-24.6837	3.4675	-11.6593	-5.2961

Table 6.5: EDC muscle MDF differences in activity unit transitions

Pianist Group											
ECU	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F
Δ PE1-FE1	1.2180	12.4980	X	-17.6681	21.8763	12.8837	26.1842	10.8608	-4.4348	9.6194	36.7554
Δ FE1-PE2	-14.9748	-13.9250	X	18.2605	-6.6112	-11.3410	-7.7621	-2.7748	2.2288	-10.8272	-12.3384
Δ PE2-FE2	13.7623	10.0936	X	-12.7766	15.1525	15.5130	28.8644	4.1743	5.9173	19.2314	34.2442
Δ FE2-PE3	-15.3603	-14.7551	X	25.8487	-11.5748	-13.1115	-3.7735	12.8915	-9.0908	-5.2074	-15.2310

Control Group					
ECU	P9052F	C9231F	C9291M	C10101F	C10102F
Δ PE1-FE1	21.7405	48.9047	34.6400	2.2891	10.1363
Δ FE1-PE2	-13.1236	-26.4782	-11.6111	-5.0495	0.5444
Δ PE2-FE2	24.8837	33.9071	28.9777	11.6207	-10.2867
Δ FE2-PE3	-18.9155	-15.0083	-24.3264	5.2462	11.2522

Table 6.6: ECU muscle MDF differences in activity unit transitions

Pianist Group											
FDS	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F
Δ PE1-FE1	11.5274	-5.2665	19.2150	8.0928	-3.3649	0.3625	14.9186	15.7565	0.7108	-24.7695	19.6494
Δ FE1-PE2	4.0297	-29.5934	14.2716	-59.2177	-1.5278	-39.4010	-24.6134	-43.1729	-25.3912	-21.6964	-24.7100
Δ PE2-FE2	7.9169	-6.4910	17.8152	11.6008	-4.4693	10.8956	23.3334	7.7526	3.8895	-13.3175	21.9872
Δ FE2-PE3	-5.1332	-33.2605	-19.7474	-59.7901	3.3683	-39.7032	-27.1139	-51.6876	-26.6305	-18.9668	-21.2391
Control Group											
FDS	C9052F	C9231F	C9291M	C10101F	C10102F						
Δ PE1-FE1	7.5236	-24.7366	25.5992	30.2370	1.6607						
Δ FE1-PE2	-30.2099	8.1025	-48.0011	-47.8990	-39.3620						
Δ PE2-FE2	22.5676	-16.6048	17.1691	27.8388	13.4156						
Δ FE2-PE3	-29.0844	2.1526	-35.8479	-52.0311	-35.1674						

Table 6.7: FDS muscle MDF differences in activity unit transitions

Pianist Group											
FCU	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F
Δ PE1-FE1	4.9919	-7.5749	32.3650	22.3718	5.5013	47.9450	15.4963	18.0892	-15.7938	-16.1998	45.6524
Δ FE1-PE2	-6.7224	-8.7969	29.3884	-41.7557	-3.6513	-60.0883	-8.1217	-36.4374	-13.0665	12.3636	-28.9529
Δ PE2-FE2	19.3829	0.1820	49.1337	9.5715	12.2453	54.9848	13.7450	18.5404	-24.6511	-23.5284	48.0730
Δ FE2-PE3	-5.8411	-13.6664	-10.1684	-45.9028	-1.6903	-67.5221	-11.8179	-37.2505	-22.2353	11.9918	-45.4583
Control Group											
FCU	C9052F	C9231F	C9291M	C10101F	C10102F						
Δ PE1-FE1	-11.6833	-25.1372	-24.6580	3.2295	14.3580						
Δ FE1-PE2	7.6762	6.9761	-18.1990	-37.3174	-14.5640						
Δ PE2-FE2	-11.0103	-19.0727	-35.9945	4.4133	7.7151						
Δ FE2-PE3	0.8084	-0.2586	-3.5931	-38.3805	-21.4053						

Table 6.8: FCU muscle MDF differences in activity unit transitions

A two-tailed exact goodness-of-fit test was performed in Excel to determine the statistical significance of the MDF differences in activity unit transitions. A null hypothesis, that there would not be any significant differences was used. P-values related to positive differences between activity units (which indicates potential fatigue accumulation) are listed in Table 6.9. Activity unit transitions between the first fatiguing exercise session and the second piano exercise session (Δ FE1-PE2) and between the second fatiguing exercise session and the third piano exercise session (Δ FE2-PE3) were not included in the table because they did not show any statistically significant results.

		Activity Unit Transitions					
		All Participants		Pianist Group		Control Group	
		Δ PE1-FE1	Δ PE2-FE2	Δ PE1-FE1	Δ PE2-FE2	Δ PE1-FE1	Δ PE2-FE2
Muscle	EDC	0.8036	0.4545	1.0000	0.2266	1.0000	1.0000
	ECU	0.0074	0.0074	0.1094	0.0215	0.0625	0.3750
	FDS	0.0768	0.0768	0.2266	0.2266	0.3750	0.3750
	FCU	0.4545	0.2101	0.2266	0.0654	1.0000	1.0000

Table 6.9: P-values related to MDF differences in activity unit transitions

There were some statistically significant results determined in the difference of MDF value in the activity unit transitions. Cells highlighted in green indicate that there is strong evidence to reject the null hypothesis at a confidence level of 97% (or better). Cells highlighted in yellow, show moderate evidence against the null hypothesis in favour of the research hypothesis at about a 92% confidence level. Cells that have not been highlighted show no evidence against the null hypothesis and appear to be consistent with null hypothesis.

6.4 Discussion

Statistical analysis of the cumulative MDF trends during the fatiguing exercise showed some consistencies across the fatiguing exercise activity units. For all of the participants, there was strong evidence ($P < 0.04$) of cumulative muscle fatigue in the EDC and ECU muscles across the static contraction sections (FE1S+FE2S), and in the EDC and FDS muscles across the dynamic contraction sections (FE1D+FE2D). There was also moderate evidence ($P < 0.08$) of cumulative muscle fatigue in the FCU muscle across the static contraction sections (FE1S+FE2S), and in the EDC muscle across all of the fatiguing exercise sections (FE1S+FE1D+FE2S+FE2D) for all of the participants. The Pianist Group showed moderate evidence ($P < 0.07$) of cumulative muscle fatigue in the

FCU muscle across the static contraction sections (FE1S+FE2S), and in the EDC and FDS muscles across the dynamic contraction sections (FE1D+FE2D). The Control Group showed moderate evidence ($P < 0.07$) of cumulative muscle fatigue in the EDC and ECU muscles across the static contraction sections (FE1S+FE2S), and in the FDS muscle across the dynamic contraction sections (FE1D+FE2D).

Comparison of the Pianist Group to the Control Group (to determine if there were any differences between them with respect to the development of cumulative muscle fatigue), showed no evidence against the null hypothesis and therefore there is no evidence that one group is more likely than the other to develop cumulative muscle fatigue across the fatiguing exercise activity units.

As stated in the results section, there were not any statistically significant results determined from the analysis of the MDF trends across the piano exercise activity units. However, it was shown that 4 of 5 participants in the Control Group developed muscle fatigue across all of the piano exercise sessions in the FDS muscle, and 7 of 11 participants in the Pianist Group showed muscle recovery in the EDC muscle across all of the piano exercise sessions. These results provide further evidence of the physiologic changes that can occur to the muscles through years of piano training giving pianists the ability to recover quickly after their muscles are fatigued. It also provides evidence that non-pianists (with untrained muscles) are more likely to fatigue while performing the same activity as the pianists.

It is important to determine if cumulative muscle fatigue has developed because it makes motor unit recovery slower and subsequent contractions are affected. Lack of full recovery between activity units could result in more rapid development of muscle fatigue and require greater effort to maintain the task performance.

Statistical analysis of the MDF differences in activity unit transitions showed some significant results. Strong evidence ($P < 0.01$) was shown in the ECU muscle in the transition from the first piano exercise session (PE1) to the first fatiguing exercise session (FE1), and in the transition from the second piano exercise session (PE2) to the second fatiguing exercise session (FE2) for all participants. Strong evidence ($P < 0.03$) was also shown in the ECU muscle of the Pianist Group in the transition from the second piano exercise session (PE2) to the second fatiguing exercise session (FE2). Moderate evidence ($P < 0.07$) was shown in the ECU muscle of the Control Group in the transition from the first piano exercise session (PE1) to the first fatiguing exercise session (FE1). Moderate evidence ($P < 0.08$) was also shown in the FDS muscle of all participants in the transitions from the first piano exercise session (PE1) to the first fatiguing exercise session (FE1), and in the transition from the second piano exercise session (PE2) to the second fatiguing exercise session (FE2). Additionally, moderate evidence ($P < 0.07$) was shown in the FCU muscle of the pianists in the transition from the second piano exercise session (PE2) to the second fatiguing exercise session (FE2). It is possible that the differences in the MDF values between activity units was simply related to the change of activity, but there is some evidence both statistically and visually that indicates the likelihood of residual fatigue carrying over from one activity unit to the next.

6.5 Conclusion

It was determined that there is some evidence of residual fatigue carried over from one activity unit to the next resulting in cumulative muscle fatigue. Across fatiguing exercise activity units, strong evidence ($P < 0.04$) of cumulative muscle fatigue was shown in the EDC and ECU muscles in the static contraction sections, and in the EDC and FDS muscles in the dynamic contraction sections for all participants. There was also moderate evidence ($P < 0.08$) that the EDC muscle developed muscle fatigue across all fatiguing exercise sections in all of the participants.

There was not statistically significant evidence of residual fatigue across the piano exercise activity units, but it was shown that 4 of 5 participants in the Control Group developed muscle fatigue across all of the piano exercise sessions in the FDS muscle, and 7 of 11 participants in the Pianist Group showed muscle recovery in the EDC muscle across all of the piano exercise sessions.

Significant results were also found for MDF differences at activity unit transitions.

Strong evidence ($P < 0.01$) was shown that at both transitions from piano exercise to fatiguing exercise sessions, the ECU muscle exhibited residual fatigue in all participants.

7 Chapter: Conclusions and Recommendations

7.1 Summary of Results

It was determined with significant evidence ($P < 0.04$), that muscle fatigue is detectable in the forearm muscles (especially in the extensor muscles) during the fatiguing exercise. There was no evidence that muscle fatigue is more likely to occur in one participant group or the other, but weak evidence ($P < 0.09$) was shown that pianists are more likely to have a declining total power trend in the FCU muscle (during the static contraction section of the second fatiguing exercise (FE2S)). It was also determined that residual fatigue was carried across the fatiguing exercise activity units. In all of the participants, strong evidence ($P < 0.04$) was shown for the EDC and ECU muscles in the static contraction sections, and for the EDC and FDS muscles in the dynamic contraction sections. There was also moderate evidence ($P < 0.08$) that the EDC muscle carried residual fatigue across all fatiguing exercise sections in all of the participants.

During the first piano exercise session (PE1), it was determined with significant evidence ($P < 0.01$) that muscle fatigue is likely to occur in the ECU muscle of all participants. Strong evidence ($P < 0.03$) was also shown that muscle recovery is likely to occur in the extensor muscles (EDC and ECU) of the pianists during the second and third piano exercise sessions (PE2 and PE3). It is important because it shows prevention of fatigue accumulation (in the extensor muscles) and the ability to recover from muscle fatigue.

Strong evidence ($P < 0.02$) also showed that the total power trend would decline in the EDC muscle of the pianists in the first piano exercise session (PE1), and moderate evidence of the same result in the third piano exercise session (PE3). The contradiction of declining power despite the muscles showing muscle recovery was assumed to be related to efficiencies developed during piano training requiring less energy expenditure.

Comparisons between the Pianist Group and the Control Group displayed significant differences ($P < 0.03$) in the flexor muscles (FDS and FCU) during the second piano exercise (PE2). The Control Group exhibited muscle fatigue, whereas the majority of participants in the Pianist Group showed muscle recovery. Additionally, weak evidence ($P < 0.095$) showed that the Control Group was more likely to have an increasing total power trend in the FDS and FCU muscles during the second piano exercise (PE2) indicating that untrained muscles need to recruit additional motor units and increase firing rates in order to maintain the task performance when muscles are fatigued.

Significant results were also found for MDF differences at activity unit transitions. Strong evidence ($P < 0.01$) was shown that in both transitions from piano exercise to fatiguing exercise sessions, the ECU muscle showed residual fatigue in all participants.

Differences between the two participant groups were shown with respect to the development of muscle fatigue. While not statistically significant, there was evidence of residual fatigue across the piano exercise activity units: 4 of 5 participants in the Control Group developed muscle fatigue in the FDS muscle across all of the piano exercise

sessions, and 7 of 11 participants in the Pianist Group showed muscle recovery in the EDC muscle across all of the piano exercise sessions.

In the scope of this research, it was not possible to quantitatively analyse the effect on how a pianist plays when their muscles are fatigued, but responses to the questions collected from the Pianist Group in Appendix C provide some insight on the effects felt from muscle fatigue and how they thought it impacted their piano playing. The responses support the theory that different muscle activation patterns were used to perform the fatiguing exercise (based on where the participants felt their muscles fatigue) and most of the pianists felt it impacted the accuracy of their piano playing.

7.2 Conclusions

This research shows that muscle fatigue is detectable using the methodology outlined in Chapter 3, and that there are differences in the development of muscle fatigue between pianists and non-pianists warranting further study. Submaximal contractions (such as piano playing) may be maintained for a long period time and the onset of fatigue may not limit the ability of an individual to perform the task. Comments from pianists about the effects felt from muscle fatigue show a common perception about its impact on the accuracy of their piano playing. Therefore, detecting manifestations of muscle fatigue during piano playing may be useful for determining the effect piano playing has on the forearm muscles and identifying those with potential risk for injury.

7.3 Recommendations for Future Study

The following are recommendations for future work based on the findings of this thesis as well as other studies of muscle fatigue.

1. Changes in Movement Patterns

Changes in movement patterns with fatigue are well documented for a variety of different tasks. Fatigue alters muscle-activation-patterns and degrades performance in single-joint arm movements. However, submaximal contractions can be sustained after the onset of muscle fatigue so the effect of muscle fatigue may not be apparent. Use of reflective markers, placed on the right arm segments could be helpful to define the movements of the body segments in addition to tracking muscle fatigue.^{6, 40, 83}

2. Gender Differences

The most consistently reported finding in studies looking at PRMDs in pianists was that females were more susceptible to developing PRMDs than males. It is inferred that the higher rate of PRMDs is related to hand size and joint laxity, as well as biological differences such as strength, size, and hormones. However, previous work has also shown that females exhibit increased endurance during sub-maximal contractions, isometric contractions, and dynamic tasks in comparison to males. There were not enough male participants in our study to determine if gender had an impact on the results.^{1, 3, 5, 10, 42, 81, 89, 92, 93}

3. Hand Dominance

All of the participants in our study were right-handed except for one person in the Pianist Group and one person in the Control Group. Left-handed and right-handed persons exhibit similar abilities when performing manual tasks, but the motor control of the non-dominant hand of left-handed persons has been shown to be superior to that of right-handed persons. Strategies used to perform fatiguing contractions have also been shown to vary with the handedness of the individual. Handedness may influence how a person plays the piano and performs fatiguing contractions, but we did not have enough left-handed participants in our study to determine if hand dominance impacted the results.^{19, 87}

4. Post-Activation Potentiation (PAP)

It has been shown in athletic exercise studies that potentiation of the muscle (increase in performance capability) can occur after a period of sub-maximal contractions. This phenomenon may occur through the training undertaken by pianists and would be worth investigating to determine any benefit for piano playing performance. The benefit from sub-maximal contractions is dependent on the rest time after a training activity. If the person rests too long, the potentiation benefit dissipates, but not resting long enough results in the accumulation of fatigue. It would also be beneficial to evaluate the same participant on several different days to determine any differences in their muscle activation patterns and better evaluate the accumulation of fatigue in the muscles.^{36, 57, 104}

5. Alternative Method for Muscle Fatigue Estimation

Instead of using FFT to convert the EMG signals into the power spectrum, an alternative method that has shown to be more accurate for fatigue tracking during dynamic contractions could be used. Examples of these methods are: wavelet transform analysis, multi-fractal detrended fluctuation analysis, and Lempel-Ziv complexity measure.^{42, 105, 106}

6. Testing Additional Muscles

Fatigue of a single muscle group may cause changes in muscle activation patterns and create imbalances between agonist-antagonist muscle pairs. When high precision is required for a task, the body compensates by increasing limb stiffness such that performance can be maintained, but at the expense of a higher workload (greater energy requirements) of the muscles. As well, the CNS may redistribute muscle activity to non-fatigued muscles in order to protect fatigued muscles.

Testing all three of the major forearm muscle pairs (EDC/FDS, ECU/FCU, ECR/FCR) may provide more information about the redistribution of muscle activity during muscle fatigue and the occurrence of co-contraction. As well, because it is difficult to identify individual forearm muscles due to their size and close proximity, testing the additional muscle pair would help with the interpretation of the muscle activation patterns (in flexion and extension).^{40, 41, 69}

Appendix A

Actions of Muscles Controlling the Wrist and Hand¹⁴

Muscles of the Wrist and Hand	
Muscles of the Wrist	
Muscle	Action
Flexors	
Flexor carpi ulnaris	Flexion of wrist; ulnar deviation of hand
Flexor carpi radialis	Flexion of wrist; radial deviation of hand
Palmaris longus	Tension of the palmar fascia
Extensors	
Extensor carpi radialis longus and brevis	Extension of wrist; radial deviation of hand
Extensor carpi ulnaris and brevis	Extension of wrist; ulnar deviation of hand
Pronators-supinators	
Pronator teres	Forearm pronation
Pronator quadratus	Forearm pronation
Supinator	Forearm supination
Brachioradialis	Pronation or supination, depending on position of forearm
Muscles of the Hand	
Muscle	Action
Extrinsic Muscles	
Flexors	
Flexor digitorum superficialis	Flexion of PIP and MCP joints
Flexor digitorum profundus	Flexion of DIP, PIP, and MCP joints
Flexor pollicis longus	Flexion of IP and MCP joints of thumb
Extensors	
Extensor pollicis longus	Extension of IP and MCP joints of thumb; secondary adduction of the thumb
Extensor pollicis brevis	Extension of MCP joint of thumb
Abductor pollicis longus	Abduction of thumb
Extensor indicis proprius	Extension of index finger
Extensor digitorum communis	Extension of fingers
Extensor digiti quinti proprius	Extension of V finger
Intrinsic Muscles	
Interossei (all)	Extension of PIP and DIP joints and flexion of MCP joints
Dorsal interossei	Spread of index and ring fingers away from long finger
Palmar interossei	Adduction of index, ring, and little fingers toward long finger
Lumbricals	Extension of PIP and DIP joints and flexion of MCP 2–5 finger
Thenar Muscles	
Abductor pollicis brevis	Abduction of thumb
Flexor pollicis brevis	Flexion and rotation of thumb
Opponens pollicis	Rotation of first metacarpal toward palm
Hypothenar Muscles	
Abductor digiti quinti	Abduction of little finger (extension of PIP and DIP joints)
Flexor digiti quinti brevis	Flexion of proximal phalanx of little finger and forward rotation of fifth metacarpal
Adductor pollicis	Adduction of thumb

Diagram with Anatomical Terms for Wrist and Hand Movements¹⁰⁷

Appendix B

Letter of Information, Consent Form and General Information Questionnaire

Letter of Information

Dear Participant,

We are conducting a ground-breaking collaborative research study to investigate the high incidence of injury among pianists. Despite many years of training and careful practice, researchers have found that approximately 60% of active pianists experience playing-related injuries at some point in their careers; musculoskeletal injuries of the forearm being the most common. We are investigating the relationship between the muscles used to play the piano and the effect of fatigue on those muscles. The research study includes contributions from researchers in the field of Biomechanics and Biological Signals at Carleton University and the University of Ottawa's Piano Pedagogy Research Laboratory. We are currently recruiting participants to take part in the study and need your assistance. Below you will find a description of the study and the tasks involved. Should you wish to volunteer to take part in the study, or if you would like more information, please do not hesitate to contact Karen McCarthy at karen_mccarthy@carleton.ca.

Research Project: Detection of Forearm Muscle Fatigue during Piano Playing Using Surface Electromyography (sEMG) Analysis

Target Group:

We will be recruiting two separate groups for the study.

Participants in the **Control Group** will need to:

- a. Be 18 years of age or older;
- b. Have no piano playing experience or less than a year of piano playing experience;
- c. Have no current or past forearm injuries or experience any forearm pain when completing daily tasks, typing or playing the piano.

Participants in the **Pianist Group** will need to:

- a. Be 18 years of age or older;
- b. Have more than 15 years of piano playing experience or be studying piano at a university undergraduate or graduate level;
- c. Have no current or past forearm injuries or experience any forearm pain when completing daily tasks, typing or playing the piano.

Objective of the Study:

The objective of the study is to examine the activity of the forearm muscles during piano playing using surface electromyography (sEMG). The results will be used to determine if muscle fatigue is detectable during piano playing, if pianists and non-pianists fatigue at the same rate and if there is an effect on how a pianist plays when their muscles are fatigued.

Location:

The experiments will take place at the University of Ottawa's Piano Pedagogy Research Laboratory located at:

Perez Hall, Room 204
50 University Street
Ottawa, ON K1N 6N5

Tasks Completed by Participants:

Participants in the study will be assigned general alphanumerical identification so that their identity will remain confidential. The pianist group will be asked to complete a general information questionnaire regarding their piano playing habits and experience. Participants will then be seated and the EMG electrodes will be placed on the surface of the forearm. The location for the electrode placement will be determined by anatomical markers and verified by asking the participants to perform muscle isolating movements and gentle palpation of the muscles. Participants will then be asked to 1) play a piano exercise 2) perform a muscle fatiguing exercise for two minutes 3) repeat the piano exercise 4) perform the muscle fatiguing exercise until told to stop or until the participant elects to stop 5) repeat the piano exercise a final time. The piano exercise consists of a five finger pattern (no lateral movement of the hand) in 16th notes at 60 bpm and in the pianist group a two octave C Major Scale will also be incorporated into the exercise. In the muscle fatiguing exercise the participants will grasp and lift a weight with their palm of their hand facing downward and complete repetitions lifting the weight upwards with only movement occurring at the wrist. A metronome beating at 60 beats per minute will be used in both the piano exercise and muscle fatiguing exercise to help the participants monitor the rate of their contractions and movements. The EMG data will be collected during both the piano exercise and muscle fatiguing exercise. Determining if muscle fatigue is present will not be possible until the data is analysed, but the raw EMG data will provide an indication of how and when the forearm muscles are recruited during the piano and muscle fatiguing exercises. Musical instrument digital instrument (MIDI) data and video data will also be recorded in order to have auditory and visual records of the piano exercises. Photographs of the participant may be taken, but these will only show the placement of the equipment on the participant and the experiment set-up; facial features of the participant will not be recorded in photographs or video. The total time commitment for the participant will be approximately 30-45 minutes.

Risks the Participant May Face:

Participants may experience a small risk of physical discomfort. During the experimental sessions, surface electrodes will be applied to the participant's forearm and will be used to collect electromyographic (EMG) data. The electrodes are small, non-invasive and are secured to the surface of the skin using a non-toxic adhesive. When the electrodes are removed the participant may experience some discomfort similar to the discomfort felt when removing an adhesive bandage. The participants may also experience some discomfort during the muscle fatiguing exercise and piano playing session due to the repetitive movements involved. The discomfort felt would be similar to that felt when doing repetitive bicep curls or other type of muscle endurance exercise. The fatiguing exercise is designed to make the forearm muscles tired; there is not any pain associated with muscle fatiguing exercise or piano playing tasks.

Benefits of the Research Project:

The study stands to benefit the participants (piano players) and the piano playing community. The detection of muscle fatigue during piano playing has not been verified. The focus of this work is to develop and validate a methodology to determine if muscle fatigue is detectable during piano playing, if pianists and non-pianists fatigue at the same rate and to determine if there is an effect on how a pianist plays when their muscles are fatigued. Information about the effect of muscle fatigue during piano playing could be used to determine potential for injury and injury prevention strategies.

Withdrawal from the Research Project:

Participation in this study is strictly voluntary. Participants can choose to withdraw from the study at any time while the experimental session is being conducted. After the experimental session, participants will not be able to withdraw from the study since it will not be possible to identify the data associated with them. Participants will be informed again at the beginning of the experimental session that they can stop the experiment at any time. Participants do not have to provide any reason or justification to withdraw.

Participant Privacy Protection:

Data collected for participants in the study will only be identified by general alphanumeric identification. Any personal information collected (name, gender, year of birth and email) will only be used in the context of this study and the Consent Form containing this information will be kept outside the laboratory under lock and key in the Research Team's office. At the conclusion of each day that experiments are conducted, the Consent Forms will be removed from the laboratory so that it will not be possible to link participants to the data collected. Consent Forms will be destroyed at the conclusion of the research project. Photographs, audio and video data collected will only be associated with the alphanumeric identification of the participant and will be securely stored under lock and key in the Research Team's Office on a password protected computer. Photographs and video will only show the placement of the equipment on the participant; facial features of the participant will not be recorded. Data collected for the research study (excluding personal information) will be kept indefinitely. Only authorized members of the Research Team will have access to the data.

Compensation:

Participation in this study is strictly on a voluntary basis. Participants will not receive any form of compensation for participating in this study.

How to obtain a copy of the results:

We would be pleased to share the results of this project with you. In order to receive a summary of the results, please contact Karen McCarthy at karen_mccarthy@carleton.ca.

Ethical Concerns:

This project was reviewed and received ethics clearance by the Carleton University Research Ethics Committee. If you have any ethical concerns regarding participation in this study, please contact the Research Ethics Board Chair at:

Professor Andy Adler, Chair
Carleton University Research Ethics Committee
Office of Research Services
Carleton University
1125 Colonel By Drive
Ottawa, Ontario K1S 5B6
Tel: 613-520-2517
E-mail: ethics@carleton.ca

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Dr. Gilles Comeau, Ph.D.
Faculty of Arts - School of Music
University of Ottawa
Phone: 613-562-5800 x3483
Email: gcomeau@uOttawa.ca

Consent Form:

Please indicate which group you would like to participate in:

☐ Control Group

☐ Pianist Group

I, _____, confirm that I have read and understand the information presented in the **Letter of Information** about the research project. I voluntarily agree to participate in this research project, knowing that I can withdraw from the study at any time while the experimental session is being conducted and do not have to provide any reason or justification to withdraw.

Section to be completed by the Participant	
First name:	Last name:
Gender: Male / Female	Year of Birth:
Email (optional):	
Signature:	Date (dd/mm/yyyy):
Section to be completed by the Researcher	
Name:	
Signature:	Date (dd/mm/yyyy):

Consent Form

Research Project: Detection of Forearm Muscle Fatigue during Piano Playing Using Surface Electromyography (sEMG) Analysis

Target Group: Please indicate which group you would like to participate in:

☐ Control Group

☐ Pianist Group

I, _____, confirm that I have read and understand the information presented in the **Letter of Information** about the research project. I voluntarily agree to participate in this research project, knowing that I can withdraw from the study at any time while the experimental session is being conducted and do not have to provide any reason or justification to withdraw.

Section to be completed by the Participant	
First name:	Last name:
Gender: Male / Female	Year of Birth:
Email (optional):	
Signature:	Date (dd/mm/yyyy):
Section to be completed by the Researcher	
Name:	
Signature:	Date (dd/mm/yyyy):

General Information Questionnaire

Research Project: Detection of Forearm Muscle Fatigue during Piano Playing Using Surface Electromyography (sEMG) Analysis

Please do not sign your name on this form.

Section to be completed by the Participant
Age at which piano studies began:
Current age:
Level of performance reached before university (i.e. Grade 10 / Royal Conservatory):
Last exam passed (Grade / Institution):
Year in undergraduate music program: or Year in graduate music program:
Frequency of piano practice (days/week):
Number of practice sessions per day:
Duration of each practice session:
Approximate time of day of practice session(s):
Do you experience any pain during or after playing piano?
Dominant writing hand:

Appendix C

Participant Demographic Information and Questionnaire Responses

Pianist Group					
Gender	Age	Handedness	Years of Practice	Frequency of Practice	Duration of Practice
female	21	right	15	6 days/week, 3x/day	1-2 hours
female	30	right	22	6 days/week, 3x/day	2-3 hours
female	23	right	19	3-5 days/week, 1-2x/day	0.5-2 hours
male	27	right	11	3 days/week, 1x/day	1 hour
female	40	right	35	2 days/week, 1x/day	0.5 hours
female	23	right	17	1-2 days/week, 1x/day	0.5-1 hours
female	60	left	40	4-5 days/week, 1x/day	0.5-1 hours
female	22	right	12	5 days/week, 1-2x/day	2 hours
female	40	right	34	7 days/week, 2x/day	0.3 hours
female	31	right	28	2 days/week, 1-2x/day	0.7 hours
female	19	right	10	7 days/week, 2-4x/day	2 hours

Control Group		
Gender	Age	Handedness
female	24	right
male	25	right
female	19	right
male	26	left
female	30	right
female	23	right

Questions asked to the Pianist Group:
1. Why did you stop the fatiguing exercise the second time? Describe what you felt.
Responses:
I couldn't lift the weight as high and got uncomfortable.
My muscles felt weaker.
My arm felt hot and I had no more energy to lift the weight.
I felt a little muscle soreness, but didn't feel like I needed to stop. My shoulder muscles got more tired than my forearms.
I felt muscle strain on both sides of the elbow and my wrist felt heavy.
My muscles got uncomfortable and felt tight.
My muscles got warm and I could feel the burn on sides of my arm. My wrist was also cracking and it got worse.
It was hard to hold my hand up and I felt a burn in the arm. The second repetition of the exercise felt shorter.
I felt tension in my shoulder not in my forearm.
I felt muscle pain in my bicep more than in my forearms.
I felt strain on my upper arm close to the tricep and back of the shoulder. The forearm muscles felt hot.
My wrist felt tired and it got cold after playing.
2. Do you think it had an effect on your piano playing? Describe how.
Responses:
Yes, it changed the timing and I anticipated the beat.
Yes, it was easier to play afterwards, but harder to keep tempo. I felt like I needed to slow down
No, it didn't effect my piano playing
If I did it for longer then yes it would have.
Yes, I felt like my hands were kept closer to keys and I didn't have to lift the fingers as high.
Yes, it slowed my reaction time down.
Yes, my fingers weren't as accurate and it made my hand shake.
Yes, I felt shaky at first, but then playing felt more relaxed.
Yes, it changed the tone. I felt more warmed up after lifting weight.
Yes, my timing was uneven, I was trying to reoperate, my muscles were trying to relax, and I felt a loss of finger control.
Yes, I felt shaky playing keys, and had an uneven tempo. I kept thinking about how to preserve energy and put more weight on the keys.
My arm felt heavier and I produced a different sound (louder dynamic, fuller tone).

Appendix D

Delsys[®] Bagnoli[™]-8 Desktop EMG System and Delsys[®] DE-2.1 Sensor Specifications ¹⁰⁰

Products

EMG Sensors

Desktop EMG Systems

Handheld EMG Systems

EMGworks[®] Software

Hardware Integration

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[User's Guide](#)
[Specifications](#)
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Bagnoli[™] Desktop System Specifications

System	Bagnoli-16	Bagnoli-8	Bagnoli-4
Mechanical			
Main Amplifier			
Dimensions	406 x 152 x 70 mm	205 x 108 x 57 mm	100 x 65 x 40 mm
Mass	2.1 kg	0.8 kg	0.5 kg
Enclosure Material	ABS Plastic	ABS Plastic	ABS Plastic
Temperature Range	0-40° C	0-40° C	0-40° C
Output Connector	(16) BNC, SCSI-68	(8) BNC, SCSI-68	(4) BNC, SCSI-68
Input Module			
Dimensions	89 x 83 x 32 mm	89 x 83 x 32 mm	61 x 58 x 25 mm
Mass	100 g	100 g	64 g
Enclosure Material	FR-ABS Plastic	FR-ABS Plastic	FR-ABS Plastic
No. of Inputs	16 EMG/Auxiliary	8 EMG/Auxiliary	4 EMG/Auxiliary
Input Module Cable			
Length	7.5 m (up to 15 m)	7.5 m (up to 15 m)	7.5 m (up to 15 m)
Diameter	6.5 mm	6.5 mm	-
Jacket Material	PVC	PVC	PVC
Electrical			
Overall EMG Amplification	100, 1000, 10000 custom $\pm 1\%$	100, 1000, 10000 custom $\pm 1\%$	100, 1000, 10000 custom $\pm 1\%$
AUX Amplification	1 custom $\pm 1\%$	1 custom $\pm 1\%$	1 custom $\pm 1\%$
EMG Bandwidth	20-450 Hz $\pm 10\%$	20-450 Hz $\pm 10\%$	20-450 Hz $\pm 10\%$
AUX Bandwidth	DC/20 - 450/2000 Hz $\pm 10\%$	DC/20 - 450/2000 Hz $\pm 10\%$	DC/20 - 450/2000 Hz $\pm 10\%$
Bandwidth Roll-off	80 dB/decade	80 dB/decade	80 dB/decade
Overall Noise	≤ 1.2 μ V (RMS, R.T.I.)	≤ 1.2 μ V (RMS, R.T.I.)	≤ 1.2 μ V (RMS, R.T.I.)
Power Consumption	5.8 W (typical)	4.2 W (typical)	2.9 W (typical)
Leakage Current	<100 μ A	<100 μ A	<100 μ A
Voltage Isolation	6000 VDC, 4200 VAC (RMS)	6000 VDC, 4200 VAC (RMS)	6000 VDC, 4200 VAC (RMS)
Line Error Range	50, 60 Hz	50, 60 Hz	50, 60 Hz
Saturation Error Threshold	± 4.8 V (output)	± 4.8 V (output)	± 4.8 V (output)
Medical Device Conformity	IEC 601-1, CE mark, 510K	IEC 601-1, CE mark, 510K	IEC 601-1, CE mark, 510K
Classification	Class I (93/42/EEC), TypeBF	Class I (93/42/EEC), TypeBF	Class I (93/42/EEC), TypeBF

N.B. Delsys reserves the right to change Features and Specifications without notice.

Products

EMG Sensors

Desktop EMG Systems

Handheld EMG Systems

EMGworks® Software

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Surface EMG Sensor Specifications

EMG Sensors	DE-2.1
System	Bagnoli™
Type	Single Differential
Mechanical	
Number of Contacts	2
Contact Dimension	10.0 x 1.0 mm
Contact Spacing	10.0 mm
Contact Material	99.9% Ag
Detection Area	10 mm ²
Case Dimensions	41 x 20 x 5 mm
Case Material	Polycarbonate
Cable Length	1.67 m
Connector	Hypertronics D04
Temperature Range	0-40 °C
Electrical	
Preamplifier Gain	10 V/V ±1%
Bandwidth	open
Noise	1.2uV (RMS, R.T.I.)
CMRR (60/10 Hz)	-92 dB (typical)
Power Consumption	20 mW (typical)
Input Impedance	>10 ¹⁵ Ω //0.2pF

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Site Map

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Appendix E

EMG Signal Segmentation Data

P9052F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	32450	40530	FFP1	36.5	32.45	40.53	8.08	
	Scales	40530	61640		51.1	40.53	61.64	21.11	
	Five Finger Pattern	61640	69670	FFP2	65.7	61.64	69.67	8.03	
	Five Finger Pattern	73710	81710	FFP3	77.7	73.71	81.71	8.00	
	Scales	81710	102850		92.3	81.71	102.85	21.14	
	Five Finger Pattern	102850	110800	FFP4	106.8	102.85	110.80	7.95	
	Five Finger Pattern	114900	122900	FFP5	118.9	114.90	122.90	8.00	
	Scales	122900	144050		133.5	122.90	144.05	21.15	
	Five Finger Pattern	144050	152100	FFP6	148.1	144.05	152.10	8.05	
Fatiguing Exercise 1	isotonic	158800	168400	FEIT1	163.6	158.80	168.40	9.60	
	isometric/isotonic	168900	179100	FEIM1	174.0	168.90	179.10	10.20	over held
	isotonic	179300	188600	FEIT2	184.0	179.30	188.60	9.30	
	isometric/isotonic	189000	198700	FEIM2	193.9	189.00	198.70	9.70	
	isotonic	199000	207500	FEIT3	203.3	199.00	207.50	8.50	missed 1 pulse
	isometric/isotonic	208100	218700	FEIM3	213.4	208.10	218.70	10.60	over held
	isotonic	219100	227600	FEIT4	223.4	219.10	227.60	8.50	missed 1 pulse
	isometric/isotonic	228100	238700	FEIM4	233.4	228.10	238.70	10.60	over held
	isotonic	239100	247800	FEIT5	243.5	239.10	247.80	8.70	missed 1 pulse
	isometric/isotonic	248200	258800	FEIM5	253.5	248.20	258.80	10.60	over held
	isotonic	259200	268800	FEIT6	264.0	259.20	268.80	9.60	
	isometric/isotonic	252600	254600	FEIM6	274.7	269.30	280.00	10.70	over held
Piano Exercise 2	Five Finger Pattern	285600	293600	FFP21	289.6	285.60	293.60	8.00	
	Scales	293600	321900		307.8	293.60	321.90	28.30	did 1 extra scale
	Five Finger Pattern	321900	329900	FFP22	325.9	321.90	329.90	8.00	
	Five Finger Pattern	334000	342000	FFP23	338.0	334.00	342.00	8.00	
	Scales	342000	363100		352.6	342.00	363.10	21.10	
	Five Finger Pattern	363100	371100	FFP24	367.1	363.10	371.10	8.00	
	Five Finger Pattern	375200	383200	FFP25	379.2	375.20	383.20	8.00	
Fatiguing Exercise 2	Scales	383200	404250		393.7	383.20	404.25	21.05	
	Five Finger Pattern	404250	412300	FFP26	408.3	404.25	412.30	8.05	
	isotonic	420200	429700	FEIT21	425.0	420.20	429.70	9.50	
	isometric/isotonic	430100	439700	FEIM21	434.9	430.10	439.70	9.60	
	isotonic	440200	449600	FEIT22	444.9	440.20	449.60	9.40	
	isometric/isotonic	450100	459900	FEIM22	455.0	450.10	459.90	9.80	
	isotonic	460300	468800	FEIT23	464.6	460.30	468.80	8.50	missed 1 pulse
	isometric/isotonic	469300	479800	FEIM23	474.6	469.30	479.80	10.50	
	isotonic	480200	490100	FEIT24	485.2	480.20	490.10	9.90	
	isometric/isotonic	490600	498100	FEIM24	494.4	490.60	498.10	7.50	under held
	isometric/isotonic	499300	507100	FEIM24b	503.2	499.30	507.10	7.80	did an extra hold
	isotonic	507500	517100	FEIT25	512.3	507.50	517.10	9.60	
Piano Exercise 3	isometric/isotonic	517600	527400	FEIM25	522.5	517.60	527.40	9.80	
	isotonic	527800	537100	FEIT26	532.5	527.80	537.10	9.30	
	isometric/isotonic	537600	547600	FEIM26	542.6	537.60	547.60	10.00	
	isotonic	547800	557400	FEIT27	552.6	547.80	557.40	9.60	
	isometric/isotonic	557800	567400	FEIM27	562.6	557.80	567.40	9.60	
	Five Finger Pattern	573000	581000	FFP31	577.0	573.00	581.00	8.00	
	Scales	581000	602200		591.6	581.00	602.20	21.20	
	Five Finger Pattern	602200	610300	FFP32	606.3	602.20	610.30	8.10	
	Five Finger Pattern	614400	622300	FFP33	618.4	614.40	622.30	7.90	
	Scales	622300	643400		632.9	622.30	643.40	21.10	
	Five Finger Pattern	643400	651500	FFP34	647.5	643.40	651.50	8.10	
	Five Finger Pattern	655500	663500	FFP35	659.5	655.50	663.50	8.00	
	Scales	663500	684700		674.1	663.50	684.70	21.20	
	Five Finger Pattern	684700	692600	FFP36	688.7	684.70	692.60	7.90	

P9191F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	5460	13640	FFP1	9.6	5.46	13.64	8.18	
	Scales	13640	34530		24.1	13.64	34.53	20.89	
	Five Finger Pattern	34530	42780	FFP2	38.7	34.53	42.78	8.25	
	Five Finger Pattern	46710	54800	FFP3	50.8	46.71	54.80	8.09	
	Scales	54800	75950		65.4	54.80	75.95	21.15	
	Five Finger Pattern	75950	83950	FFP4	80.0	75.95	83.95	8.00	
	Five Finger Pattern	87920	95940	FFP5	91.9	87.92	95.94	8.02	
Piano Exercise 1	Scales	95940	116750		106.3	95.94	116.75	20.81	
	Five Finger Pattern	116750	124900	FFP6	120.8	116.75	124.90	8.15	
Fatiguing Exercise 1	isotonic	133600	148600	FEIT1	141.1	133.60	148.60	15.00	slow completing repetitions under held
	isometric/isotonic	150100	157700	FEIM1	153.9	150.10	157.70	7.60	
	isotonic	158400	167700	FEIT2	163.1	158.40	167.70	9.30	
	isometric/isotonic	168200	177900	FEIM2	173.1	168.20	177.90	9.70	
	isotonic	178400	187600	FEIT3	183.0	178.40	187.60	9.20	
	isometric/isotonic	188000	197500	FEIM3	192.8	188.00	197.50	9.50	
	isotonic	198300	207700	FEIT4	203.0	198.30	207.70	9.40	
	isometric/isotonic	208100	217900	FEIM4	213.0	208.10	217.90	9.80	
	isotonic	218400	227700	FEIT5	223.1	218.40	227.70	9.30	
	isometric/isotonic	228200	237900	FEIM5	233.1	228.20	237.90	9.70	
	isotonic	238300	247800	FEIT6	243.1	238.30	247.80	9.50	
	isometric/isotonic	248300	258100	FEIM6	253.2	248.30	258.10	9.80	
	isotonic	258700	267900	FEIT7	263.3	258.70	267.90	9.20	1 extra repetition of IT and IM
	isometric/isotonic	268400	278200	FEIM7	273.3	268.40	278.20	9.80	
Piano Exercise 2	Five Finger Pattern	282900	290950	FFP21	286.9	282.90	290.95	8.05	
	Scales	290950	312000		301.5	290.95	312.00	21.05	
	Five Finger Pattern	312000	320000	FFP22	316.0	312.00	320.00	8.00	
	Five Finger Pattern	324100	332100	FFP23	328.1	324.10	332.10	8.00	
	Scales	332100	353050		342.6	332.10	353.05	20.95	
	Five Finger Pattern	353050	361300	FFP24	357.2	353.05	361.30	8.25	
	Five Finger Pattern	365300	373300	FFP25	369.3	365.30	373.30	8.00	
Piano Exercise 2	Scales	373300	394450		383.9	373.30	394.45	21.15	
	Five Finger Pattern	394450	402500	FFP26	398.5	394.45	402.50	8.05	
Fatiguing Exercise 2	isotonic	409700	418600	FEIT21	414.2	409.70	418.60	8.90	fast completing repetitions
	isometric/isotonic	419100	428700	FEIM21	423.9	419.10	428.70	9.60	
	isotonic	429300	438400	FEIT22	433.9	429.30	438.40	9.10	
	isometric/isotonic	438900	448900	FEIM22	443.9	438.90	448.90	10.00	
	isotonic	449500	458900	FEIT23	454.2	449.50	458.90	9.40	
	isometric/isotonic	459300	468800	FEIM23	464.1	459.30	468.80	9.50	
	isotonic	469400	478500	FEIT24	474.0	469.40	478.50	9.10	
	isometric/isotonic	479000	489000	FEIM24	484.0	479.00	489.00	10.00	
	isotonic	489500	498600	FEIT25	494.1	489.50	498.60	9.10	
	isometric/isotonic	499200	509100	FEIM25	504.2	499.20	509.10	9.90	
	isotonic	509600	518700	FEIT26	514.2	509.60	518.70	9.10	
	isometric/isotonic	519200	529100	FEIM26	524.2	519.20	529.10	9.90	
Piano Exercise 3	Five Finger Pattern	532000	540100	FFP31	536.1	532.00	540.10	8.10	
	Scales	540100	560950		550.5	540.10	560.95	20.85	
	Five Finger Pattern	560950	569300	FFP32	565.1	560.95	569.30	8.35	
	Five Finger Pattern	573300	581350	FFP33	577.3	573.30	581.35	8.05	
	Scales	581350	602500		591.9	581.35	602.50	21.15	
	Five Finger Pattern	602500	610500	FFP34	606.5	602.50	610.50	8.00	
	Five Finger Pattern	614500	622500	FFP35	618.5	614.50	622.50	8.00	
Piano Exercise 3	Scales	622500	643650		633.1	622.50	643.65	21.15	
	Five Finger Pattern	643650	651700	FFP36	647.7	643.65	651.70	8.05	

P9192F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	5480	13480	FFP1	9.5	5.48	13.48	8.00	
	Scales	13480	34600		24.0	13.48	34.60	21.12	
	Five Finger Pattern	34600	42600	FFP2	38.6	34.60	42.60	8.00	
	Five Finger Pattern	46670	54690	FFP3	50.7	46.67	54.69	8.02	
	Scales	54690	75780		65.2	54.69	75.78	21.09	
	Five Finger Pattern	75780	83840	FFP4	79.8	75.78	83.84	8.06	
	Five Finger Pattern	87890	95890	FFP5	91.9	87.89	95.89	8.00	
	Scales	95890	117000		106.4	95.89	117.00	21.11	
	Five Finger Pattern	117000	125000	FFP6	121.0	117.00	125.00	8.00	
Fatiguing Exercise 1	isotonic	132400	141300	FEIT1	136.9	132.40	141.30	8.90	fast completing repetitions
	isometric/isotonic	141700	151300	FEIM1	146.5	141.70	151.30	9.60	
	isotonic	151800	161400	FEIT2	156.6	151.80	161.40	9.60	
	isometric/isotonic	161900	171600	FEIM2	166.8	161.90	171.60	9.70	
	isotonic	171900	181500	FEIT3	176.7	171.90	181.50	9.60	
	isometric/isotonic	181900	191500	FEIM3	186.7	181.90	191.50	9.60	
	isotonic	192000	201500	FEIT4	196.8	192.00	201.50	9.50	
	isometric/isotonic	202000	212100	FEIM4	207.1	202.00	212.10	10.10	over held
	isotonic	212400	221700	FEIT5	217.1	212.40	221.70	9.30	
	isometric/isotonic	222100	231800	FEIM5	227.0	222.10	231.80	9.70	
	isotonic	232400	241700	FEIT6	237.1	232.40	241.70	9.30	
	isometric/isotonic	252600	254600	FEIM6	247.1	242.20	252.00	9.80	
Piano Exercise 2	Five Finger Pattern	258700	266700	FFP21	262.7	258.70	266.70	8.00	
	Scales	266700	287800		277.3	266.70	287.80	21.10	
	Five Finger Pattern	287800	295800	FFP22	291.8	287.80	295.80	8.00	
	Five Finger Pattern	299900	307900	FFP23	303.9	299.90	307.90	8.00	
	Scales	307900	329000		318.5	307.90	329.00	21.10	
	Five Finger Pattern	329000	337100	FFP24	333.1	329.00	337.10	8.10	
	Five Finger Pattern	341100	349100	FFP25	345.1	341.10	349.10	8.00	
	Scales	349100	370200		359.7	349.10	370.20	21.10	
	Five Finger Pattern	370200	378200	FFP26	374.2	370.20	378.20	8.00	
	isotonic	385100	394600	FEIT21	389.9	385.10	394.60	9.50	
	isometric/isotonic	395100	404400	FEIM21	399.8	395.10	404.40	9.30	
	isotonic	405000	414700	FEIT22	409.9	405.00	414.70	9.70	
	isometric/isotonic	415100	424600	FEIM22	419.9	415.10	424.60	9.50	
	isotonic	425100	434700	FEIT23	429.9	425.10	434.70	9.60	
	isometric/isotonic	435200	444700	FEIM23	440.0	435.20	444.70	9.50	
	isotonic	445200	454800	FEIT24	450.0	445.20	454.80	9.60	
	isometric/isotonic	455300	464700	FEIM24	460.0	455.30	464.70	9.40	
	isotonic	465300	474900	FEIT25	470.1	465.30	474.90	9.60	
	isometric/isotonic	475400	485000	FEIM25	480.2	475.40	485.00	9.60	
	isotonic	485400	495000	FEIT26	490.2	485.40	495.00	9.60	
Fatiguing Exercise 2	isometric/isotonic	495500	505100	FEIM26	500.3	495.50	505.10	9.60	
	isotonic	505500	515000	FEIT27	510.3	505.50	515.00	9.50	
	isometric/isotonic	515500	525100	FEIM27	520.3	515.50	525.10	9.60	
	isotonic	525600	535200	FEIT28	530.4	525.60	535.20	9.60	
	isometric/isotonic	535700	545200	FEIM28	540.5	535.70	545.20	9.50	
	isotonic	545600	554300	FEIT29	550.0	545.60	554.30	8.70	missed 1 pulse
	isometric/isotonic	554800	565300	FEIM29	560.1	554.80	565.30	10.50	over held
	isotonic	565800	575400	FEIT30	570.6	565.80	575.40	9.60	
	isometric/isotonic	575900	585500	FEIM30	580.7	575.90	585.50	9.60	
	isotonic	585900	595400	FEIT31	590.7	585.90	595.40	9.50	
	isometric/isotonic	596000	605400	FEIM31	600.7	596.00	605.40	9.40	
Piano Exercise 3	Five Finger Pattern	608400	616400	FFP31	612.4	608.40	616.40	8.00	
	Scales	616400	644550		630.5	616.40	644.55	28.15	did 1 extra scale
	Five Finger Pattern	644550	652600	FFP32	648.6	644.55	652.60	8.05	
	Five Finger Pattern	656600	664650	FFP33	660.6	656.60	664.65	8.05	
	Scales	664650	685700		675.2	664.65	685.70	21.05	
	Five Finger Pattern	685700	693800	FFP34	689.8	685.70	693.80	8.10	
	Five Finger Pattern	697800	705800	FFP35	701.8	697.80	705.80	8.00	
	Scales	705800	726950		716.4	705.80	726.95	21.15	
	Five Finger Pattern	726950	735000	FFP36	731.0	726.95	735.00	8.05	

P9193M	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	7370	15390	FFP1	11.4	7.37	15.39	8.02	
	Scales	15390	40510		28.0	15.39	40.51	25.12	
	Five Finger Pattern	40510	48600	FFP2	44.6	40.51	48.60	8.09	
	Five Finger Pattern	52550	60630	FFP3	56.6	52.55	60.63	8.08	
	Scales	60630	81740		71.2	60.63	81.74	21.11	
	Five Finger Pattern	81740	89760	FFP4	85.8	81.74	89.76	8.02	
	Five Finger Pattern	93740	101800	FFP5	97.8	93.74	101.80	8.06	
	Scales	101800	122900		112.4	101.80	122.90	21.10	
	Five Finger Pattern	122900	130900	FFP6	126.9	122.90	130.90	8.00	
Fatiguing Exercise 1	isotonic	137000	150600	FEIT1	143.8	137.00	150.60	13.60	slow completing repetitions
	isometric/isotonic	151500	160600	FEIM1	156.1	151.50	160.60	9.10	
	isotonic	161200	171900	FEIT2	166.6	161.20	171.90	10.70	slow completing repetitions
	isometric/isotonic	172600	181800	FEIM2	177.2	172.60	181.80	9.20	
	isotonic	182400	192300	FEIT3	187.4	182.40	192.30	9.90	
	isometric/isotonic	193500	202400	FEIM3	198.0	193.50	202.40	8.90	under held
	isotonic	203300	212400	FEIT4	207.9	203.30	212.40	9.10	missed 1 pulse
	isometric/isotonic	212900	223000	FEIM4	218.0	212.90	223.00	10.10	over held
	isotonic	223700	232300	FEIT5	228.0	223.70	232.30	8.60	missed 1 pulse
	isometric/isotonic	232800	243100	FEIM5	238.0	232.80	243.10	10.30	over held
	isotonic	243700	252200	FEIT6	248.0	243.70	252.20	8.50	missed 1 pulse
	isometric/isotonic	252600	262900	FEIM6	257.8	252.60	262.90	10.30	over held
	isotonic	263800	272300	FEIT7	268.1	263.80	272.30	8.50	missed 1 pulse
	isometric/isotonic	272800	283500	FEIM7	278.2	272.80	283.50	10.70	over held
Piano Exercise 2	Five Finger Pattern	288700	296800	FFP21	292.8	288.70	296.80	8.10	
	Scales	296800	317900		307.4	296.80	317.90	21.10	
	Five Finger Pattern	317900	325900	FFP22	321.9	317.90	325.90	8.00	
	Five Finger Pattern	329900	337950	FFP23	333.9	329.90	337.95	8.05	
	Scales	337950	359000		348.5	337.95	359.00	21.05	
	Five Finger Pattern	359000	367100	FFP24	363.1	359.00	367.10	8.10	
	Five Finger Pattern	371100	379100	FFP25	375.1	371.10	379.10	8.00	
	Scales	379100	400250		389.7	379.10	400.25	21.15	
	Five Finger Pattern	400250	408200	FFP26	404.2	400.25	408.20	7.95	
Fatiguing Exercise 2	isotonic	415000	424600	FEIT21	419.8	415.00	424.60	9.60	
	isometric/isotonic	425000	434800	FEIM21	429.9	425.00	434.80	9.80	
	isotonic	435600	445200	FEIT22	440.4	435.60	445.20	9.60	
	isometric/isotonic	445300	454900	FEIM22	450.1	445.30	454.90	9.60	
	isotonic	455600	465200	FEIT23	460.4	455.60	465.20	9.60	
	isometric/isotonic	465700	475200	FEIM23	470.5	465.70	475.20	9.50	
	isotonic	475600	484500	FEIT24	480.1	475.60	484.50	8.90	missed 1 pulse
	isometric/isotonic	484800	495200	FEIM24	490.0	484.80	495.20	10.40	over held
	isotonic	495800	504500	FEIT25	500.2	495.80	504.50	8.70	missed 1 pulse
	isometric/isotonic	504900	515500	FEIM25	510.2	504.90	515.50	10.60	over held
	isotonic	516000	524700	FEIT26	520.4	516.00	524.70	8.70	missed 1 pulse
	isometric/isotonic	525100	535200	FEIM26	530.2	525.10	535.20	10.10	over held
	isotonic	536000	544800	FEIT27	540.4	536.00	544.80	8.80	missed 1 pulse
	isometric/isotonic	545000	555600	FEIM27	550.3	545.00	555.60	10.60	over held
	isotonic	556200	564800	FEIT28	560.5	556.20	564.80	8.60	missed 1 pulse
	isometric/isotonic	565200	571700	FEIM28	568.5	565.20	571.70	6.50	under held
	isotonic	572100	583800	FEIT29	578.0	572.10	583.80	11.70	2 extra pulses
	isometric/isotonic	584200	594000	FEIM29	589.1	584.20	594.00	9.80	
	isotonic	594300	603900	FEIT30	599.1	594.30	603.90	9.60	
	isometric/isotonic	604000	614100	FEIM30	609.1	604.00	614.10	10.10	over held
	isotonic	614500	623100	FEIT31	618.8	614.50	623.10	8.60	missed 1 pulse
Piano Exercise 3	isometric/isotonic	623500	634000	FEIM31	628.8	623.50	634.00	10.50	over held
	isotonic	634500	643100	FEIT32	638.8	634.50	643.10	8.60	missed 1 pulse
	isometric/isotonic	643500	654300	FEIM32	648.9	643.50	654.30	10.80	over held
	Five Finger Pattern	659500	667600	FFP31	663.6	659.50	667.60	8.10	
	Scales	667600	688600		678.1	667.60	688.60	21.00	
	Five Finger Pattern	688600	696700	FFP32	692.7	688.60	696.70	8.10	
	Five Finger Pattern	700700	708750	FFP33	704.7	700.70	708.75	8.05	
	Scales	708750	736850		722.8	708.75	736.85	28.10	did 1 extra scale
	Five Finger Pattern	736850	744900	FFP34	740.9	736.85	744.90	8.05	
	Five Finger Pattern	749000	757000	FFP35	753.0	749.00	757.00	8.00	
	Scales	757000	778050		767.5	757.00	778.05	21.05	
	Five Finger Pattern	778050	786100	FFP36	782.1	778.05	786.10	8.05	

P9231F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	5420	13400	FFP1	9.4	5.42	13.40	7.98	
	Scales	13400	34510		24.0	13.40	34.51	21.11	
	Five Finger Pattern	34510	42510	FFP2	38.5	34.51	42.51	8.00	
	Five Finger Pattern	46640	54600	FFP3	50.6	46.64	54.60	7.96	
	Scales	54600	75740		65.2	54.60	75.74	21.14	
	Five Finger Pattern	75740	83720	FFP4	79.7	75.74	83.72	7.98	
	Five Finger Pattern	87840	95780	FFP5	91.8	87.84	95.78	7.94	
	Scales	95780	116900		106.3	95.78	116.90	21.12	
	Five Finger Pattern	116900	124900	FFP6	120.9	116.90	124.90	8.00	
Fatiguing Exercise 1	isotonic	133500	143300	FEIT1	138.4	133.50	143.30	9.80	
	isometric/isotonic	143700	153300	FEIM1	148.5	143.70	153.30	9.60	
	isotonic	154200	163800	FEIT2	159.0	154.20	163.80	9.60	
	isometric/isotonic	164300	173300	FEIM2	168.8	164.30	173.30	9.00	slightly under held
	isotonic	173900	183300	FEIT3	178.6	173.90	183.30	9.40	
	isometric/isotonic	183800	193300	FEIM3	188.6	183.80	193.30	9.50	
	isotonic	193800	203600	FEIT4	198.7	193.80	203.60	9.80	
	isometric/isotonic	203900	213200	FEIM4	208.6	203.90	213.20	9.30	
	isotonic	213800	223600	FEIT5	218.7	213.80	223.60	9.80	
	isometric/isotonic	224000	233600	FEIM5	228.8	224.00	233.60	9.60	
	isotonic	234000	243700	FEIT6	238.9	234.00	243.70	9.70	
	isometric/isotonic	244100	254600	FEIM6	249.4	244.10	254.60	10.50	over held
Piano Exercise 2	Five Finger Pattern	258600	266650	FFP21	262.6	258.60	266.65	8.05	
	Scales	266650	287750		277.2	266.65	287.75	21.10	
	Five Finger Pattern	287750	295700	FFP22	291.7	287.75	295.70	7.95	
	Five Finger Pattern	299800	307800	FFP23	303.8	299.80	307.80	8.00	
	Scales	307800	328900		318.4	307.80	328.90	21.10	
	Five Finger Pattern	328900	336900	FFP24	332.9	328.90	336.90	8.00	
	Five Finger Pattern	341000	349000	FFP25	345.0	341.00	349.00	8.00	
	Scales	349000	370100		359.6	349.00	370.10	21.10	
	Five Finger Pattern	370100	378100	FFP26	374.1	370.10	378.10	8.00	
Fatiguing Exercise 2	isotonic	383600	393400	FEIT21	388.5	383.60	393.40	9.80	
	isometric/isotonic	393900	403400	FEIM21	398.7	393.90	403.40	9.50	
	isotonic	403900	413500	FEIT22	408.7	403.90	413.50	9.60	
	isometric/isotonic	413900	423400	FEIM22	418.7	413.90	423.40	9.50	
	isotonic	423900	433600	FEIT23	428.8	423.90	433.60	9.70	
	isometric/isotonic	434000	443500	FEIM23	438.8	434.00	443.50	9.50	
	isotonic	444000	453600	FEIT24	448.8	444.00	453.60	9.60	
	isometric/isotonic	454100	463800	FEIM24	459.0	454.10	463.80	9.70	
	isotonic	464100	473800	FEIT25	469.0	464.10	473.80	9.70	
	isometric/isotonic	474200	483600	FEIM25	478.9	474.20	483.60	9.40	
	isotonic	484200	493900	FEIT26	489.1	484.20	493.90	9.70	
	isometric/isotonic	494200	504000	FEIM26	499.1	494.20	504.00	9.80	
	isotonic	504300	514000	FEIT27	509.2	504.30	514.00	9.70	
	isometric/isotonic	514300	524000	FEIM27	519.2	514.30	524.00	9.70	
	isotonic	524400	534200	FEIT28	529.3	524.40	534.20	9.80	
	isometric/isotonic	534600	544100	FEIM28	539.4	534.60	544.10	9.50	
	isotonic	544400	554100	FEIT29	549.3	544.40	554.10	9.70	
	isometric/isotonic	554500	564400	FEIM29	559.5	554.50	564.40	9.90	
Piano Exercise 3	Five Finger Pattern	569200	577100	FFP31	573.2	569.20	577.10	7.90	
	Scales	577100	598200		587.7	577.10	598.20	21.10	
	Five Finger Pattern	598200	606200	FFP32	602.2	598.20	606.20	8.00	
	Five Finger Pattern	610300	618300	FFP33	614.3	610.30	618.30	8.00	
	Scales	618300	639400		628.9	618.30	639.40	21.10	
	Five Finger Pattern	639400	647400	FFP34	643.4	639.40	647.40	8.00	
	Five Finger Pattern	651500	659500	FFP35	655.5	651.50	659.50	8.00	
	Scales	659500	680600		670.1	659.50	680.60	21.10	
	Five Finger Pattern	680600	688700	FFP36	684.7	680.60	688.70	8.10	

P9291F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	19320	27250	FFP1	23.3	19.32	27.25	7.93	
	Scales	27250	48800		38.0	27.25	48.80	21.55	
	Five Finger Pattern	48800	56480	FFP2	52.6	48.80	56.48	7.68	
	Five Finger Pattern	60540	66290	FFP3	63.4	60.54	66.29	5.75	missed 1 FFP
	Scales	66290	97610		82.0	66.29	97.61	31.32	did 1 extra scale
	Five Finger Pattern	97610	105400	FFP4	101.5	97.61	105.40	7.79	
	Five Finger Pattern	109700	117750	FFP5	113.7	109.70	117.75	8.05	
	Scales	117750	138250		128.0	117.75	138.25	20.50	
	Five Finger Pattern	138250	145900	FFP6	142.1	138.25	145.90	7.65	
	isotonic	156200	165400	FEIT1	160.8	156.20	165.40	9.20	
	isometric/isotonic	165700	175800	FEIM1	170.8	165.70	175.80	10.10	over held
	isotonic	176100	185400	FEIT2	180.8	176.10	185.40	9.30	
	isometric/isotonic	185800	195100	FEIM2	190.5	185.80	195.10	9.30	
	isotonic	195700	205300	FEIT3	200.5	195.70	205.30	9.60	
	isometric/isotonic	205600	215400	FEIM3	210.5	205.60	215.40	9.80	
	isotonic	215700	225700	FEIT4	220.7	215.70	225.70	10.00	
	isometric/isotonic	226100	235400	FEIM4	230.8	226.10	235.40	9.30	
	isotonic	235800	245600	FEIT5	240.7	235.80	245.60	9.80	
	isometric/isotonic	245900	255700	FEIM5	250.8	245.90	255.70	9.80	
	isotonic	255900	265800	FEIT6	260.9	255.90	265.80	9.90	
	isometric/isotonic	266000	276200	FEIM6	271.1	266.00	276.20	10.20	over held
Piano Exercise 2	Five Finger Pattern	285200	293900	FFP21	289.6	285.20	293.90	8.70	
	Scales	293900	321900		307.9	293.90	321.90	28.00	did 1 extra scale
	Five Finger Pattern	321900	329600	FFP22	325.8	321.90	329.60	7.70	
	Five Finger Pattern	333500	341850	FFP23	337.7	333.50	341.85	8.35	
	Scales	341850	362750		352.3	341.85	362.75	20.90	
	Five Finger Pattern	362750	370700	FFP24	366.7	362.75	370.70	7.95	
	Five Finger Pattern	374900	383000	FFP25	379.0	374.90	383.00	8.10	
	Scales	383000	403550		393.3	383.00	403.55	20.55	
	Five Finger Pattern	403550	411400	FFP26	407.5	403.55	411.40	7.85	
	isotonic	417100	426400	FEIT21	421.8	417.10	426.40	9.30	
	isometric/isotonic	426800	436500	FEIM21	431.7	426.80	436.50	9.70	
	isotonic	436900	446700	FEIT22	441.8	436.90	446.70	9.80	
	isometric/isotonic	447100	456500	FEIM22	451.8	447.10	456.50	9.40	
	isotonic	457000	466700	FEIT23	461.9	457.00	466.70	9.70	
	isometric/isotonic	467200	476600	FEIM23	471.9	467.20	476.60	9.40	
	isotonic	477000	486700	FEIT24	481.9	477.00	486.70	9.70	
	isometric/isotonic	487100	496700	FEIM24	491.9	487.10	496.70	9.60	
	isotonic	497200	506900	FEIT25	502.1	497.20	506.90	9.70	
	isometric/isotonic	507200	517000	FEIM25	512.1	507.20	517.00	9.80	
	isotonic	517400	526900	FEIT26	522.2	517.40	526.90	9.50	
	isometric/isotonic	527100	537200	FEIM26	532.2	527.10	537.20	10.10	over held
	isotonic	537400	547100	FEIT27	542.3	537.40	547.10	9.70	
	isometric/isotonic	547500	556600	FEIM27	552.1	547.50	556.60	9.10	
	Five Finger Pattern	561500	569800	FFP31	565.7	561.50	569.80	8.30	
	Scales	569800	590050		579.9	569.80	590.05	20.25	
	Five Finger Pattern	590050	597700	FFP32	593.9	590.05	597.70	7.65	
	Five Finger Pattern	602000	609550	FFP33	605.8	602.00	609.55	7.55	
	Scales	609550	635550		622.6	609.55	635.55	26.00	did 1 extra scale
	Five Finger Pattern	635550	643000	FFP34	639.3	635.55	643.00	7.45	
	Five Finger Pattern	647300	655150	FFP35	651.2	647.30	655.15	7.85	
	Scales	655150	674300		664.7	655.15	674.30	19.15	
	Five Finger Pattern	674300	681800	FFP36	678.1	674.30	681.80	7.50	

P1031F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	59620	67620	FFP1	63.6	59.62	67.62	8.00	
	Scales	67620	88280		78.0	67.62	88.28	20.66	
	Five Finger Pattern	88280	96200	FFP2	92.2	88.28	96.20	7.92	
	Five Finger Pattern	99800	108000	FFP3	103.9	99.80	108.00	8.20	
	Scales	108000	128950		118.5	108.00	128.95	20.95	
	Five Finger Pattern	128950	137000	FFP4	133.0	128.95	137.00	8.05	
	Five Finger Pattern	141100	149050	FFP5	145.1	141.10	149.05	7.95	
	Scales	149050	170150		159.6	149.05	170.15	21.10	
	Five Finger Pattern	170150	178200	FFP6	174.2	170.15	178.20	8.05	
Fatiguing Exercise 1	isotonic	183800	193700	FEIT1	188.8	183.80	193.70	9.90	
	isometric/isotonic	194100	204000	FEIM1	199.1	194.10	204.00	9.90	
	isotonic	204700	213700	FEIT2	209.2	204.70	213.70	9.00	
	isometric/isotonic	214200	224100	FEIM2	219.2	214.20	224.10	9.90	
	isotonic	224600	233800	FEIT3	229.2	224.60	233.80	9.20	
	isometric/isotonic	234300	244200	FEIM3	239.3	234.30	244.20	9.90	
	isotonic	244600	253900	FEIT4	249.3	244.60	253.90	9.30	
	isometric/isotonic	254300	264200	FEIM4	259.3	254.30	264.20	9.90	
	isotonic	264600	273900	FEIT5	269.3	264.60	273.90	9.30	
	isometric/isotonic	274400	284700	FEIM5	279.6	274.40	284.70	10.30	over held
	isotonic	285100	294000	FEIT6	289.6	285.10	294.00	8.90	
	isometric/isotonic	294400	304800	FEIM6	299.6	294.40	304.80	10.40	over held
Piano Exercise 2	Five Finger Pattern	306900	314950	FFP21	310.9	306.90	314.95	8.05	
	Scales	314950	336050		325.5	314.95	336.05	21.10	
	Five Finger Pattern	336050	344000	FFP22	340.0	336.05	344.00	7.95	
	Five Finger Pattern	348100	356100	FFP23	352.1	348.10	356.10	8.00	
	Scales	356100	377150		366.6	356.10	377.15	21.05	
	Five Finger Pattern	377150	385200	FFP24	381.2	377.15	385.20	8.05	
	Five Finger Pattern	389300	397300	FFP25	393.3	389.30	397.30	8.00	
	Scales	397300	418300		407.8	397.30	418.30	21.00	
	Five Finger Pattern	418300	426400	FFP26	422.4	418.30	426.40	8.10	did 1 extra FFP repetition
Fatiguing Exercise 2	isotonic	434200	443500	FEIT21	438.9	434.20	443.50	9.30	
	isometric/isotonic	444100	453600	FEIM21	448.9	444.10	453.60	9.50	
	isotonic	454200	463900	FEIT22	459.1	454.20	463.90	9.70	
	isometric/isotonic	464400	473900	FEIM22	469.2	464.40	473.90	9.50	
	isotonic	474400	484000	FEIT23	479.2	474.40	484.00	9.60	
	isometric/isotonic	484400	494000	FEIM23	489.2	484.40	494.00	9.60	
	isotonic	494400	504000	FEIT24	499.2	494.40	504.00	9.60	
	isometric/isotonic	504400	514400	FEIM24	509.4	504.40	514.40	10.00	
	isotonic	514700	524100	FEIT25	519.4	514.70	524.10	9.40	
	isometric/isotonic	524600	534300	FEIM25	529.5	524.60	534.30	9.70	
	isotonic	534700	544200	FEIT26	539.5	534.70	544.20	9.50	
	isometric/isotonic	544600	554000	FEIM26	549.3	544.60	554.00	9.40	
Piano Exercise 3	Five Finger Pattern	557100	565100	FFP31	561.1	557.10	565.10	8.00	
	Scales	565100	586200		575.7	565.10	586.20	21.10	
	Five Finger Pattern	586200	594200	FFP32	590.2	586.20	594.20	8.00	
	Five Finger Pattern	599300	607200	FFP33	603.3	599.30	607.20	7.90	
	Scales	607200	628400		617.8	607.20	628.40	21.20	
	Five Finger Pattern	628400	636400	FFP34	632.4	628.40	636.40	8.00	
	Five Finger Pattern	640400	648500	FFP35	644.5	640.40	648.50	8.10	
	Scales	648500	669500		659.0	648.50	669.50	21.00	
	Five Finger Pattern	669500	677700	FFP36	673.6	669.50	677.70	8.20	

P1032F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	4090	12150	FFP1	8.1	4.09	12.15	8.06	
	Scales	12150	33270		22.7	12.15	33.27	21.12	
	Five Finger Pattern	33270	41280	FFP2	37.3	33.27	41.28	8.01	
	Five Finger Pattern	45340	53400	FFP3	49.4	45.34	53.40	8.06	
	Scales	53400	74490		63.9	53.40	74.49	21.09	
	Five Finger Pattern	74490	82520	FFP4	78.5	74.49	82.52	8.03	
	Five Finger Pattern	85500	93580	FFP5	89.5	85.50	93.58	8.08	
	Scales	93580	114700		104.1	93.58	114.70	21.12	
	Five Finger Pattern	114700	122700	FFP6	118.7	114.70	122.70	8.00	
Fatiguing Exercise 1	isotonic	129500	139100	FEIT1	134.3	129.50	139.10	9.60	
	isometric/isotonic	139800	149100	FEIM1	144.5	139.80	149.10	9.30	
	isotonic	149700	159000	FEIT2	154.4	149.70	159.00	9.30	
	isometric/isotonic	159600	169100	FEIM2	164.4	159.60	169.10	9.50	
	isotonic	169700	179200	FEIT3	174.5	169.70	179.20	9.50	
	isometric/isotonic	179700	189200	FEIM3	184.5	179.70	189.20	9.50	
	isotonic	190200	199400	FEIT4	194.8	190.20	199.40	9.20	missed 1 pulse
	isometric/isotonic	199700	209300	FEIM4	204.5	199.70	209.30	9.60	
	isotonic	210000	219400	FEIT5	214.7	210.00	219.40	9.40	
	isometric/isotonic	219900	229500	FEIM5	224.7	219.90	229.50	9.60	
	isotonic	229900	239500	FEIT6	234.7	229.90	239.50	9.60	
	isometric/isotonic	239900	250200	FEIM6	245.1	239.90	250.20	10.30	
Piano Exercise 2	Five Finger Pattern	256300	264300	FFP21	260.3	256.30	264.30	8.00	
	Scales	264300	285500		274.9	264.30	285.50	21.20	
	Five Finger Pattern	285500	293500	FFP22	289.5	285.50	293.50	8.00	
	Five Finger Pattern	296500	304600	FFP23	300.6	296.50	304.60	8.10	
	Scales	304600	325650		315.1	304.60	325.65	21.05	
	Five Finger Pattern	325650	333700	FFP24	329.7	325.65	333.70	8.05	
	Five Finger Pattern	337700	345800	FFP25	341.8	337.70	345.80	8.10	
	Scales	345800	366900		356.4	345.80	366.90	21.10	
	Five Finger Pattern	366900	374900	FFP26	370.9	366.90	374.90	8.00	
Fatiguing Exercise 2	isotonic	381200	390100	FEIT21	385.7	381.20	390.10	8.90	
	isometric/isotonic	390600	400200	FEIM21	395.4	390.60	400.20	9.60	
	isotonic	401100	410200	FEIT22	405.7	401.10	410.20	9.10	
	isometric/isotonic	410700	420000	FEIM22	415.4	410.70	420.00	9.30	
	isotonic	420800	430300	FEIT23	425.6	420.80	430.30	9.50	
	isometric/isotonic	430700	440300	FEIM23	435.5	430.70	440.30	9.60	
	isotonic	440800	450400	FEIT24	445.6	440.80	450.40	9.60	
	isometric/isotonic	450800	460400	FEIM24	455.6	450.80	460.40	9.60	
	isotonic	460900	470600	FEIT25	465.8	460.90	470.60	9.70	
	isometric/isotonic	471100	480500	FEIM25	475.8	471.10	480.50	9.40	
	isotonic	481100	490700	FEIT26	485.9	481.10	490.70	9.60	
	isometric/isotonic	491100	500800	FEIM26	496.0	491.10	500.80	9.70	
Piano Exercise 3	Five Finger Pattern	504500	512550	FFP31	508.5	504.50	512.55	8.05	
	Scales	512550	533700		523.1	512.55	533.70	21.15	
	Five Finger Pattern	533700	541700	FFP32	537.7	533.70	541.70	8.00	did 1 extra FFP (excluded)
	Five Finger Pattern	547700	555800	FFP33	551.8	547.70	555.80	8.10	
	Scales	555800	576900		566.4	555.80	576.90	21.10	
	Five Finger Pattern	576900	584900	FFP34	580.9	576.90	584.90	8.00	
	Five Finger Pattern	587000	595000	FFP35	591.0	587.00	595.00	8.00	
	Scales	595000	616100		605.6	595.00	616.10	21.10	
	Five Finger Pattern	616100	624100	FFP36	620.1	616.10	624.10	8.00	

P1071F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	4220	12320	FFP1	8.3	4.22	12.32	8.10	
	Scales	12320	33390		22.9	12.32	33.39	21.07	
	Five Finger Pattern	33390	41430	FFP2	37.4	33.39	41.43	8.04	
	Five Finger Pattern	45470	53450	FFP3	49.5	45.47	53.45	7.98	
	Scales	53450	74560		64.0	53.45	74.56	21.11	
	Five Finger Pattern	74560	82660	FFP4	78.6	74.56	82.66	8.10	
	Five Finger Pattern	86680	94660	FFP5	90.7	86.68	94.66	7.98	
Fatiguing Exercise 1	Scales	94660	115700		105.2	94.66	115.70	21.04	
	Five Finger Pattern	115700	123900	FFP6	119.8	115.70	123.90	8.20	
	isotonic	131800	142300	FEIT1	137.1	131.80	142.30	10.50	slow completing 10 repetitions under held
	isometric/isotonic	143800	152500	FEIM1	148.2	143.80	152.50	8.70	
	isotonic	153400	162900	FEIT2	158.2	153.40	162.90	9.50	
	isometric/isotonic	163400	172800	FEIM2	168.1	163.40	172.80	9.40	
	isotonic	173200	182700	FEIT3	178.0	173.20	182.70	9.50	
	isometric/isotonic	183200	192700	FEIM3	188.0	183.20	192.70	9.50	
	isotonic	193200	203000	FEIT4	198.1	193.20	203.00	9.80	
	isometric/isotonic	203500	213100	FEIM4	208.3	203.50	213.10	9.60	
	isotonic	213500	223100	FEIT5	218.3	213.50	223.10	9.60	
	isometric/isotonic	223500	233100	FEIM5	228.3	223.50	233.10	9.60	
	isotonic	233500	243100	FEIT6	238.3	233.50	243.10	9.60	
	isometric/isotonic	243600	253100	FEIM6	248.4	243.60	253.10	9.50	
Piano Exercise 2	Five Finger Pattern	258400	266500	FFP21	262.5	258.40	266.50	8.10	
	Scales	266500	287600		277.1	266.50	287.60	21.10	
	Five Finger Pattern	287600	295600	FFP22	291.6	287.60	295.60	8.00	
	Five Finger Pattern	299700	307700	FFP23	303.7	299.70	307.70	8.00	
	Scales	307700	328800		318.3	307.70	328.80	21.10	
	Five Finger Pattern	328800	336800	FFP24	332.8	328.80	336.80	8.00	
	Five Finger Pattern	340900	348900	FFP25	344.9	340.90	348.90	8.00	
	Scales	348900	370000		359.5	348.90	370.00	21.10	
	Five Finger Pattern	370000	378100	FFP26	374.1	370.00	378.10	8.10	
	Five Finger Pattern	382200	390100	FFP27	386.2	382.20	390.10	7.90	
	Scales	390100	411200		400.7	390.10	411.20	21.10	
	Five Finger Pattern	411200	419300	FFP28	415.3	411.20	419.30	8.10	
Fatiguing Exercise 2	isotonic	425800	435600	FEIT21	430.7	425.80	435.60	9.80	
	isometric/isotonic	436000	445600	FEIM21	440.8	436.00	445.60	9.60	
	isotonic	446000	455700	FEIT22	450.9	446.00	455.70	9.70	
	isometric/isotonic	456100	465600	FEIM22	460.9	456.10	465.60	9.50	
	isotonic	466000	475700	FEIT23	470.9	466.00	475.70	9.70	
	isometric/isotonic	476100	485700	FEIM23	480.9	476.10	485.70	9.60	
	isotonic	486200	495900	FEIT24	491.1	486.20	495.90	9.70	
	isometric/isotonic	496300	505800	FEIM24	501.1	496.30	505.80	9.50	
	isotonic	506100	516100	FEIT25	511.1	506.10	516.10	10.00	
	isometric/isotonic	516400	525900	FEIM25	521.2	516.40	525.90	9.50	
	isotonic	526300	535800	FEIT26	531.1	526.30	535.80	9.50	
	isometric/isotonic	536300	546100	FEIM26	541.2	536.30	546.10	9.80	
	isotonic	546500	556100	FEIT27	551.3	546.50	556.10	9.60	
	isometric/isotonic	556500	566100	FEIM27	561.3	556.50	566.10	9.60	
	isotonic	566500	576300	FEIT28	571.4	566.50	576.30	9.80	
	isometric/isotonic	576600	586400	FEIM28	581.5	576.60	586.40	9.80	
	isotonic	586700	596400	FEIT29	591.6	586.70	596.40	9.70	
	isometric/isotonic	596800	606400	FEIM29	601.6	596.80	606.40	9.60	
Piano Exercise 3	Five Finger Pattern	609200	617200	FFP31	613.2	609.20	617.20	8.00	
	Scales	617200	638300		627.8	617.20	638.30	21.10	
	Five Finger Pattern	638300	646300	FFP32	642.3	638.30	646.30	8.00	
	Five Finger Pattern	650500	658400	FFP33	654.5	650.50	658.40	7.90	
	Scales	658400	679500		669.0	658.40	679.50	21.10	
	Five Finger Pattern	679500	687600	FFP34	683.6	679.50	687.60	8.10	
	Five Finger Pattern	691600	699600	FFP35	695.6	691.60	699.60	8.00	
	Scales	699600	720700		710.2	699.60	720.70	21.10	
	Five Finger Pattern	720700	728800	FFP36	724.8	720.70	728.80	8.10	

P1072F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	4510	12170	FFP1	8.3	4.51	12.17	7.66	
	Scales	12170	31950		22.1	12.17	31.95	19.78	
	Five Finger Pattern	31950	39510	FFP2	35.7	31.95	39.51	7.56	
	Five Finger Pattern	41870	49390	FFP3	45.6	41.87	49.39	7.52	
	Scales	49390	68520		59.0	49.39	68.52	19.13	
	Five Finger Pattern	68520	75960	FFP4	72.2	68.52	75.96	7.44	
	Five Finger Pattern	79550	86810	FFP5	83.2	79.55	86.81	7.26	
	Scales	86810	105450		96.1	86.81	105.45	18.64	
	Five Finger Pattern	105450	112700	FFP6	109.1	105.45	112.70	7.25	
	isotonic	117700	127100	FEIT1	122.4	117.70	127.10	9.40	
	isometric/isotonic	127400	137200	FEIM1	132.3	127.40	137.20	9.80	
	isotonic	137600	147100	FEIT2	142.4	137.60	147.10	9.50	
Fatiguing Exercise 1	isometric/isotonic	147600	157500	FEIM2	152.6	147.60	157.50	9.90	
	isotonic	157900	167400	FEIT3	162.7	157.90	167.40	9.50	
	isometric/isotonic	167800	178000	FEIM3	172.9	167.80	178.00	10.20	
	isotonic	178400	186300	FEIT4	182.4	178.40	186.30	7.90	missed 1 pulse
	isometric/isotonic	186700	198100	FEIM4	192.4	186.70	198.10	11.40	over held
	isotonic	198600	206600	FEIT5	202.6	198.60	206.60	8.00	missed 1 pulse
	isometric/isotonic	207100	219100	FEIM5	213.1	207.10	219.10	12.00	over held
	isotonic	219600	228700	FEIT6	224.2	219.60	228.70	9.10	
	isometric/isotonic	229100	239400	FEIM6	234.3	229.10	239.40	10.30	
	Five Finger Pattern	244500	251700	FFP21	248.1	244.50	251.70	7.20	
	Scales	251700	269550		260.6	251.70	269.55	17.85	
	Five Finger Pattern	269550	276700	FFP22	273.1	269.55	276.70	7.15	
Piano Exercise 2	Five Finger Pattern	279400	286550	FFP23	283.0	279.40	286.55	7.15	
	Scales	286550	304450		295.5	286.55	304.45	17.90	
	Five Finger Pattern	304450	311400	FFP24	307.9	304.45	311.40	6.95	
	Five Finger Pattern	314600	321650	FFP25	318.1	314.60	321.65	7.05	
	Scales	321650	339450		330.6	321.65	339.45	17.80	
	Five Finger Pattern	339450	346500	FFP26	343.0	339.45	346.50	7.05	
Fatiguing Exercise 2	isotonic	351700	361100	FEIT21	356.4	351.70	361.10	9.40	
	isometric/isotonic	361400	371300	FEIM21	366.4	361.40	371.30	9.90	
	isotonic	371700	381300	FEIT22	376.5	371.70	381.30	9.60	
	isometric/isotonic	381700	391400	FEIM22	386.6	381.70	391.40	9.70	
	isotonic	391600	401300	FEIT23	396.5	391.60	401.30	9.70	
	isometric/isotonic	401800	413000	FEIM23	407.4	401.80	413.00	11.20	over held
Piano Exercise 3	Five Finger Pattern	416300	423500	FFP31	419.9	416.30	423.50	7.20	
	Scales	423500	442400		433.0	423.50	442.40	18.90	
	Five Finger Pattern	442400	449900	FFP32	446.2	442.40	449.90	7.50	
	Five Finger Pattern	453500	460700	FFP33	457.1	453.50	460.70	7.20	
	Scales	460700	479300		470.0	460.70	479.30	18.60	
	Five Finger Pattern	479300	486500	FFP34	482.9	479.30	486.50	7.20	
	Five Finger Pattern	489700	496900	FFP35	493.3	489.70	496.90	7.20	
	Scales	496900	515050		506.0	496.90	515.05	18.15	
	Five Finger Pattern	515050	522300	FFP36	518.7	515.05	522.30	7.25	

P1073F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	4660	12770	FFP1	8.7	4.66	12.77	8.11	
	Scales	12770	33820		23.3	12.77	33.82	21.05	
	Five Finger Pattern	33820	41870	FFP2	37.8	33.82	41.87	8.05	
	Five Finger Pattern	45940	53960	FFP3	50.0	45.94	53.96	8.02	
	Scales	53960	76030		65.0	53.96	76.03	22.07	
	Five Finger Pattern	76030	84000	FFP4	80.0	76.03	84.00	7.97	
	Five Finger Pattern	88130	96240	FFP5	92.2	88.13	96.24	8.11	
Fatiguing Exercise 1	Scales	96240	117200		106.7	96.24	117.20	20.96	
	Five Finger Pattern	117200	125300	FFP6	121.3	117.20	125.30	8.10	
	isotonic	134100	143600	FEIT1	138.9	134.10	143.60	9.50	
	isometric/isotonic	144200	153600	FEIM1	148.9	144.20	153.60	9.40	
	isotonic	154000	163700	FEIT2	158.9	154.00	163.70	9.70	
	isometric/isotonic	164200	173700	FEIM2	169.0	164.20	173.70	9.50	
	isotonic	174300	183800	FEIT3	179.1	174.30	183.80	9.50	
Piano Exercise 2	isometric/isotonic	184400	194100	FEIM3	189.3	184.40	194.10	9.70	
	isotonic	194400	203900	FEIT4	199.2	194.40	203.90	9.50	
	isometric/isotonic	204100	213900	FEIM4	209.0	204.10	213.90	9.80	
	isotonic	214300	223000	FEIT5	218.7	214.30	223.00	8.70	missed 1 pulse
	isometric/isotonic	223500	234400	FEIM5	229.0	223.50	234.40	10.90	over held
									missed 1 full IT and IM segment
Fatiguing Exercise 2	Five Finger Pattern	238700	246800	FFP21	242.8	238.70	246.80	8.10	
	Scales	246800	268000		257.4	246.80	268.00	21.20	
	Five Finger Pattern	268000	276000	FFP22	272.0	268.00	276.00	8.00	
	Five Finger Pattern	280100	288100	FFP23	284.1	280.10	288.10	8.00	
	Scales	288100	309200		298.7	288.10	309.20	21.10	
	Five Finger Pattern	309200	317200	FFP24	313.2	309.20	317.20	8.00	
	Five Finger Pattern	321200	329300	FFP25	325.3	321.20	329.30	8.10	
Piano Exercise 3	Scales	329300	350400		339.9	329.30	350.40	21.10	
	Five Finger Pattern	350400	358400	FFP26	354.4	350.40	358.40	8.00	
	isotonic	364000	372700	FEIT21	368.4	364.00	372.70	8.70	missed 1 pulse
	isometric/isotonic	373200	383600	FEIM21	378.4	373.20	383.60	10.40	
	isotonic	384200	393800	FEIT22	389.0	384.20	393.80	9.60	
	isometric/isotonic	394300	402100	FEIM22	398.2	394.30	402.10	7.80	under held
	isotonic	402400	414000	FEIT23	408.2	402.40	414.00	11.60	did 2 extra pulses
Fatiguing Exercise 2	isometric/isotonic	414600	424000	FEIM23	419.3	414.60	424.00	9.40	
	isotonic	424300	433900	FEIT24	429.1	424.30	433.90	9.60	
	isometric/isotonic	434400	445000	FEIM24	439.7	434.40	445.00	10.60	
	isotonic	445200	453000	FEIT25	449.1	445.20	453.00	7.80	missed 2 pulses
	isometric/isotonic	453500	464100	FEIM25	458.8	453.50	464.10	10.60	over held
	isotonic	464200	473200	FEIT26	468.7	464.20	473.20	9.00	missed 1 pulse
	isometric/isotonic	473700	484400	FEIM26	479.1	473.70	484.40	10.70	over held
Piano Exercise 3	isotonic	484500	493300	FEIT27	488.9	484.50	493.30	8.80	missed 1 pulse
	isometric/isotonic	493700	504100	FEIM27	498.9	493.70	504.10	10.40	over held
	Five Finger Pattern	510000	518100	FFP31	514.1	510.00	518.10	8.10	
	Scales	518100	539200		528.7	518.10	539.20	21.10	
	Five Finger Pattern	539200	547300	FFP32	543.3	539.20	547.30	8.10	
	Five Finger Pattern	551400	559400	FFP33	555.4	551.40	559.40	8.00	
	Scales	559400	580400		569.9	559.40	580.40	21.00	
Fatiguing Exercise 2	Five Finger Pattern	580400	588500	FFP34	584.5	580.40	588.50	8.10	
	Five Finger Pattern	592500	600600	FFP35	596.6	592.50	600.60	8.10	
	Scales	600600	621700		611.2	600.60	621.70	21.10	
	Five Finger Pattern	621700	629700	FFP36	625.7	621.70	629.70	8.00	

C9052F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	19070	26930	FFP1	23.0	19.07	26.93	7.86	
	Five Finger Pattern	26930	34740	FFP2	30.8	26.93	34.74	7.81	
	Five Finger Pattern	34740	42400	FFP3	38.6	34.74	42.40	7.66	
	Five Finger Pattern	42400	50050	FFP4	46.2	42.40	50.05	7.65	
	Five Finger Pattern	50050	57620	FFP5	53.8	50.05	57.62	7.57	
	Five Finger Pattern	57620	65130	FFP6	61.4	57.62	65.13	7.51	
	Five Finger Pattern	65130	72760	FFP7	68.9	65.13	72.76	7.63	
	Five Finger Pattern	72760	80320	FFP8	76.5	72.76	80.32	7.56	
	Five Finger Pattern	80320	87940	FFP9	84.1	80.32	87.94	7.62	
	Five Finger Pattern	87940	95530	FFP10	91.7	87.94	95.53	7.59	
	Five Finger Pattern	95530	103150	FFP11	99.3	95.53	103.15	7.62	
	Five Finger Pattern	103150	110850	FFP12	107.0	103.15	110.85	7.70	
	Five Finger Pattern	110850	118450	FFP13	114.7	110.85	118.45	7.60	
	Five Finger Pattern	118450	126150	FFP14	122.3	118.45	126.15	7.70	
	Five Finger Pattern	126150	133750	FFP15	130.0	126.15	133.75	7.60	
Fatiguing Exercise 1	isotonic	140900	152600	FEIT1	146.8	140.90	152.60	11.70	slow completing repetitions
	isometric/isotonic	153800	164000	FEIM1	158.9	153.80	164.00	10.20	over held
	isotonic	165000	175000	FEIT2	170.0	165.00	175.00	10.00	
	isometric/isotonic	176600	184300	FEIM2	180.5	176.60	184.30	7.70	under held
	isotonic	184900	193800	FEIT3	189.4	184.90	193.80	8.90	fast completing repetitions
	isometric/isotonic	194900	204200	FEIM3	199.6	194.90	204.20	9.30	
	isotonic	204600	213900	FEIT4	209.3	204.60	213.90	9.30	
	isometric/isotonic	214800	224500	FEIM4	219.7	214.80	224.50	9.70	
	isotonic	224800	234100	FEIT5	229.5	224.80	234.10	9.30	
	isometric/isotonic	234600	243900	FEIM5	239.3	234.60	243.90	9.30	
	isotonic	244600	254200	FEIT6	249.4	244.60	254.20	9.60	
	isometric/isotonic	254700	262600	FEIM6	258.7	254.70	262.60	7.90	under held
Piano Exercise 2	Five Finger Pattern	266800	274200	FFP21	270.5	266.80	274.20	7.40	
	Five Finger Pattern	274200	281550	FFP22	277.9	274.20	281.55	7.35	
	Five Finger Pattern	281550	288700	FFP23	285.1	281.55	288.70	7.15	
	Five Finger Pattern	288700	295900	FFP24	292.3	288.70	295.90	7.20	
	Five Finger Pattern	295900	303100	FFP25	299.5	295.90	303.10	7.20	
	Five Finger Pattern	303100	310300	FFP26	306.7	303.10	310.30	7.20	
	Five Finger Pattern	310300	317600	FFP27	314.0	310.30	317.60	7.30	
	Five Finger Pattern	317600	324950	FFP28	321.3	317.60	324.95	7.35	
	Five Finger Pattern	324950	332200	FFP29	328.6	324.95	332.20	7.25	
	Five Finger Pattern	332200	339500	FFP30	335.9	332.20	339.50	7.30	
	Five Finger Pattern	339500	346700	FFP31	343.1	339.50	346.70	7.20	
	Five Finger Pattern	346700	353850	FFP32	350.3	346.70	353.85	7.15	
	Five Finger Pattern	353850	361000	FFP33	357.4	353.85	361.00	7.15	
	Five Finger Pattern	361000	368100	FFP34	364.6	361.00	368.10	7.10	
	Five Finger Pattern	368100	375200	FFP35	371.7	368.10	375.20	7.10	
Fatiguing Exercise 2	isotonic	384000	393400	FEIT21	388.7	384.00	393.40	9.40	
	isometric/isotonic	394000	403900	FEIM21	399.0	394.00	403.90	9.90	
	isotonic	404300	413900	FEIT22	409.1	404.30	413.90	9.60	
	isometric/isotonic	414400	424000	FEIM22	419.2	414.40	424.00	9.60	
	isotonic	424500	434100	FEIT23	429.3	424.50	434.10	9.60	
	isometric/isotonic	434500	444100	FEIM23	439.3	434.50	444.10	9.60	
	isotonic	444600	454100	FEIT24	449.4	444.60	454.10	9.50	
	isometric/isotonic	454700	464200	FEIM24	459.5	454.70	464.20	9.50	
	isotonic	464800	474300	FEIT25	469.6	464.80	474.30	9.50	
	isometric/isotonic	474700	484500	FEIM25	479.6	474.70	484.50	9.80	
	isotonic	484800	494300	FEIT26	489.6	484.80	494.30	9.50	
	isometric/isotonic	496700	504500	FEIM26	500.6	496.70	504.50	7.80	under held
	isotonic	505100	514400	FEIT27	509.8	505.10	514.40	9.30	
	isometric/isotonic	514800	524700	FEIM27	519.8	514.80	524.70	9.90	
	isotonic	525100	534500	FEIT28	529.8	525.10	534.50	9.40	
	isometric/isotonic	535200	544500	FEIM28	539.9	535.20	544.50	9.30	
Piano Exercise 3	Five Finger Pattern	548000	555000	FFP41	551.5	548.00	555.00	7.00	
	Five Finger Pattern	555000	562150	FFP42	558.6	555.00	562.15	7.15	
	Five Finger Pattern	562150	569050	FFP43	565.6	562.15	569.05	6.90	
	Five Finger Pattern	569050	575950	FFP44	572.5	569.05	575.95	6.90	
	Five Finger Pattern	575950	582650	FFP45	579.3	575.95	582.65	6.70	
	Five Finger Pattern	582650	589350	FFP46	586.0	582.65	589.35	6.70	
	Five Finger Pattern	589350	596050	FFP47	592.7	589.35	596.05	6.70	
	Five Finger Pattern	596050	602650	FFP48	599.4	596.05	602.65	6.60	
	Five Finger Pattern	602650	609250	FFP49	606.0	602.65	609.25	6.60	
	Five Finger Pattern	609250	615850	FFP50	612.6	609.25	615.85	6.60	
	Five Finger Pattern	615850	622450	FFP51	619.2	615.85	622.45	6.60	
	Five Finger Pattern	622450	629150	FFP52	625.8	622.45	629.15	6.70	
	Five Finger Pattern	629150	635850	FFP53	632.5	629.15	635.85	6.70	
	Five Finger Pattern	635850	642550	FFP54	639.2	635.85	642.55	6.70	
	Five Finger Pattern	642550	649100	FFP55	645.8	642.55	649.10	6.55	

C9231F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	7820	14670	FFP1	11.2	7.82	14.67	6.85	
	Five Finger Pattern	14670	22320	FFP2	18.5	14.67	22.32	7.65	
	Five Finger Pattern	22320	30030	FFP3	26.2	22.32	30.03	7.71	
	Five Finger Pattern	30030	37780	FFP4	33.9	30.03	37.78	7.75	
	Five Finger Pattern	37780	45810	FFP5	41.8	37.78	45.81	8.03	
	Five Finger Pattern	45810	54000	FFP6	49.9	45.81	54.00	8.19	
	Five Finger Pattern	54000	63960	FFP7	59.0	54.00	63.96	9.96	
	Five Finger Pattern	63960	71900	FFP8	67.9	63.96	71.90	7.94	
	Five Finger Pattern	71900	79810	FFP9	75.9	71.90	79.81	7.91	
	Five Finger Pattern	79810	87600	FFP10	83.7	79.81	87.60	7.79	
	Five Finger Pattern	87600	95330	FFP11	91.5	87.60	95.33	7.73	
	Five Finger Pattern	95330	102950	FFP12	99.1	95.33	102.95	7.62	
	Five Finger Pattern	102950	110450	FFP13	106.7	102.95	110.45	7.50	
	Five Finger Pattern	110450	118300	FFP14	114.4	110.45	118.30	7.85	
	Five Finger Pattern	118300	126100	FFP15	122.2	118.30	126.10	7.80	
Fatiguing Exercise 1	isotonic	131700	141400	FEIT1	136.6	131.70	141.40	9.70	
	isometric/isotonic	141800	151400	FEIM1	146.6	141.80	151.40	9.60	
	isotonic	152000	161400	FEIT2	156.7	152.00	161.40	9.40	
	isometric/isotonic	161900	171600	FEIM2	166.8	161.90	171.60	9.70	
	isotonic	172200	181700	FEIT3	177.0	172.20	181.70	9.50	
	isometric/isotonic	182200	191900	FEIM3	187.1	182.20	191.90	9.70	
	isotonic	192300	201700	FEIT4	197.0	192.30	201.70	9.40	
	isometric/isotonic	202100	212000	FEIM4	207.1	202.10	212.00	9.90	
	isotonic	212600	221900	FEIT5	217.3	212.60	221.90	9.30	
	isometric/isotonic	222200	231900	FEIM5	227.1	222.20	231.90	9.70	
	isotonic	232400	241900	FEIT6	237.2	232.40	241.90	9.50	
	isometric/isotonic	242300	252400	FEIM6	247.4	242.30	252.40	10.10	over held
Piano Exercise 2	Five Finger Pattern	260500	268350	FFP21	264.4	260.50	268.35	7.85	
	Five Finger Pattern	268350	275750	FFP22	272.1	268.35	275.75	7.40	
	Five Finger Pattern	275750	283300	FFP23	279.5	275.75	283.30	7.55	
	Five Finger Pattern	283300	290550	FFP24	286.9	283.30	290.55	7.25	
	Five Finger Pattern	290550	298000	FFP25	294.3	290.55	298.00	7.45	
	Five Finger Pattern	298000	305250	FFP26	301.6	298.00	305.25	7.25	
	Five Finger Pattern	305250	312550	FFP27	308.9	305.25	312.55	7.30	
	Five Finger Pattern	312550	319950	FFP28	316.3	312.55	319.95	7.40	
	Five Finger Pattern	319950	327500	FFP29	323.7	319.95	327.50	7.55	
	Five Finger Pattern	327500	334950	FFP30	331.2	327.50	334.95	7.45	
	Five Finger Pattern	334950	342350	FFP31	338.7	334.95	342.35	7.40	
	Five Finger Pattern	342350	349800	FFP32	346.1	342.35	349.80	7.45	
	Five Finger Pattern	349800	357250	FFP33	353.5	349.80	357.25	7.45	
	Five Finger Pattern	357250	365150	FFP34	361.2	357.25	365.15	7.90	
	Five Finger Pattern	365150	373000	FFP35	369.1	365.15	373.00	7.85	
Fatiguing Exercise 2	isotonic	378600	388100	FEIT21	383.4	378.60	388.10	9.50	
	isometric/isotonic	388600	398200	FEIM21	393.4	388.60	398.20	9.60	
	isotonic	398700	408300	FEIT22	403.5	398.70	408.30	9.60	
	isometric/isotonic	408600	418200	FEIM22	413.4	408.60	418.20	9.60	
	isotonic	418700	428200	FEIT23	423.5	418.70	428.20	9.50	
	isometric/isotonic	428600	438100	FEIM23	433.4	428.60	438.10	9.50	
	isotonic	438700	448400	FEIT24	443.6	438.70	448.40	9.70	
	isometric/isotonic	448900	458400	FEIM24	453.7	448.90	458.40	9.50	
	isotonic	458700	468400	FEIT25	463.6	458.70	468.40	9.70	
	isometric/isotonic	468800	478400	FEIM25	473.6	468.80	478.40	9.60	
	isotonic	478800	488500	FEIT26	483.7	478.80	488.50	9.70	
	isometric/isotonic	488900	499100	FEIM26	494.0	488.90	499.10	10.20	over held
	isotonic	499300	508700	FEIT27	504.0	499.30	508.70	9.40	
	isometric/isotonic	509100	518700	FEIM27	513.9	509.10	518.70	9.60	
	isotonic	519200	528700	FEIT28	524.0	519.20	528.70	9.50	
	isometric/isotonic	529100	539000	FEIM28	534.1	529.10	539.00	9.90	
Piano Exercise 3	Five Finger Pattern	544900	552300	FFP41	548.6	544.90	552.30	7.40	
	Five Finger Pattern	552300	559500	FFP42	555.9	552.30	559.50	7.20	
	Five Finger Pattern	559500	566800	FFP43	563.2	559.50	566.80	7.30	
	Five Finger Pattern	566800	574350	FFP44	570.6	566.80	574.35	7.55	
	Five Finger Pattern	574350	581850	FFP45	578.1	574.35	581.85	7.50	
	Five Finger Pattern	581850	589350	FFP46	585.6	581.85	589.35	7.50	
	Five Finger Pattern	589350	596700	FFP47	593.0	589.35	596.70	7.35	
	Five Finger Pattern	596700	604150	FFP48	600.4	596.70	604.15	7.45	
	Five Finger Pattern	604150	611400	FFP49	607.8	604.15	611.40	7.25	
	Five Finger Pattern	611400	618650	FFP50	615.0	611.40	618.65	7.25	
	Five Finger Pattern	618650	626200	FFP51	622.4	618.65	626.20	7.55	
	Five Finger Pattern	626200	633650	FFP52	629.9	626.20	633.65	7.45	
	Five Finger Pattern	633650	641150	FFP53	637.4	633.65	641.15	7.50	
	Five Finger Pattern	641150	648650	FFP54	644.9	641.15	648.65	7.50	
	Five Finger Pattern	648650	656400	FFP55	652.5	648.65	656.40	7.75	

C9291M	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	9480	17690	FFP1	13.6	9.48	17.69	8.21	
	Five Finger Pattern	17690	25610	FFP2	21.7	17.69	25.61	7.92	
	Five Finger Pattern	25610	33820	FFP3	29.7	25.61	33.82	8.21	
	Five Finger Pattern	33820	42090	FFP4	38.0	33.82	42.09	8.27	
	Five Finger Pattern	42090	50130	FFP5	46.1	42.09	50.13	8.04	
	Five Finger Pattern	50130	58360	FFP6	54.2	50.13	58.36	8.23	
	Five Finger Pattern	58360	66410	FFP7	62.4	58.36	66.41	8.05	
	Five Finger Pattern	66410	74560	FFP8	70.5	66.41	74.56	8.15	
	Five Finger Pattern	74560	82340	FFP9	78.5	74.56	82.34	7.78	
	Five Finger Pattern	82340	90020	FFP10	86.2	82.34	90.02	7.68	
	Five Finger Pattern	90020	98230	FFP11	94.1	90.02	98.23	8.21	
	Five Finger Pattern	98230	106300	FFP12	102.3	98.23	106.30	8.07	
	Five Finger Pattern	106300	114350	FFP13	110.3	106.30	114.35	8.05	
	Five Finger Pattern	114350	122300	FFP14	118.3	114.35	122.30	7.95	
	Five Finger Pattern	122300	130600	FFP15	126.5	122.30	130.60	8.30	
Fatiguing Exercise 1	isotonic	133500	143600	FEIT1	138.6	133.50	143.60	10.10	over held
	isometric/isotonic	144000	153700	FEIM1	148.9	144.00	153.70	9.70	
	isotonic	154300	163500	FEIT2	158.9	154.30	163.50	9.20	
	isometric/isotonic	164000	173700	FEIM2	168.9	164.00	173.70	9.70	
	isotonic	174300	183500	FEIT3	178.9	174.30	183.50	9.20	
	isometric/isotonic	183900	193800	FEIM3	188.9	183.90	193.80	9.90	
	isotonic	194400	203700	FEIT4	199.1	194.40	203.70	9.30	
	isometric/isotonic	204200	213700	FEIM4	209.0	204.20	213.70	9.50	
	isotonic	214500	223900	FEIT5	219.2	214.50	223.90	9.40	
	isometric/isotonic	224400	234000	FEIM5	229.2	224.40	234.00	9.60	
	isotonic	234500	244200	FEIT6	239.4	234.50	244.20	9.70	
	isometric/isotonic	244600	253900	FEIM6	249.3	244.60	253.90	9.30	
Piano Exercise 2	Five Finger Pattern	262100	269900	FFP21	266.0	262.10	269.90	7.80	
	Five Finger Pattern	269900	277200	FFP22	273.6	269.90	277.20	7.30	
	Five Finger Pattern	277200	284550	FFP23	280.9	277.20	284.55	7.35	
	Five Finger Pattern	284550	291850	FFP24	288.2	284.55	291.85	7.30	
	Five Finger Pattern	291850	299200	FFP25	295.5	291.85	299.20	7.35	
	Five Finger Pattern	299200	306750	FFP26	303.0	299.20	306.75	7.55	
	Five Finger Pattern	306750	314450	FFP27	310.6	306.75	314.45	7.70	
	Five Finger Pattern	314450	321900	FFP28	318.2	314.45	321.90	7.45	
	Five Finger Pattern	321900	329650	FFP29	325.8	321.90	329.65	7.75	
	Five Finger Pattern	329650	337300	FFP30	333.5	329.65	337.30	7.65	
	Five Finger Pattern	337300	344750	FFP31	341.0	337.30	344.75	7.45	
	Five Finger Pattern	344750	352000	FFP32	348.4	344.75	352.00	7.25	
	Five Finger Pattern	352000	359450	FFP33	355.7	352.00	359.45	7.45	
	Five Finger Pattern	359450	366850	FFP34	363.2	359.45	366.85	7.40	
	Five Finger Pattern	366850	374500	FFP35	370.7	366.85	374.50	7.65	
Fatiguing Exercise 2	isotonic	379300	388300	FEIT21	383.8	379.30	388.30	9.00	
	isometric/isotonic	388800	398800	FEIM21	393.8	388.80	398.80	10.00	
	isotonic	399400	408700	FEIT22	404.1	399.40	408.70	9.30	
	isometric/isotonic	409300	418800	FEIM22	414.1	409.30	418.80	9.50	
	isotonic	419400	428800	FEIT23	424.1	419.40	428.80	9.40	
	isometric/isotonic	429300	438900	FEIM23	434.1	429.30	438.90	9.60	
	isotonic	439500	449000	FEIT24	444.3	439.50	449.00	9.50	
	isometric/isotonic	449400	459000	FEIM24	454.2	449.40	459.00	9.60	
	isotonic	459700	469100	FEIT25	464.4	459.70	469.10	9.40	
	isometric/isotonic	469500	479000	FEIM25	474.3	469.50	479.00	9.50	
	isotonic	479700	489100	FEIT26	484.4	479.70	489.10	9.40	
	isometric/isotonic	489500	499100	FEIM26	494.3	489.50	499.10	9.60	
	isotonic	499700	509200	FEIT27	504.5	499.70	509.20	9.50	
	isometric/isotonic	509700	519100	FEIM27	514.4	509.70	519.10	9.40	
	isotonic	519700	529200	FEIT28	524.5	519.70	529.20	9.50	
	isometric/isotonic	529600	539400	FEIM28	534.5	529.60	539.40	9.80	
	isotonic	539900	549400	FEIT29	544.7	539.90	549.40	9.50	
	isometric/isotonic	549800	559500	FEIM29	554.7	549.80	559.50	9.70	
	isotonic	560000	569700	FEIT30	564.9	560.00	569.70	9.70	
	isometric/isotonic	570100	579900	FEIM30	575.0	570.10	579.90	9.80	
	isotonic	580300	589400	FEIT31	584.9	580.30	589.40	9.10	
	isometric/isotonic	589800	599100	FEIM31	594.5	589.80	599.10	9.30	
Piano Exercise 3	Five Finger Pattern	604600	612450	FFP41	608.5	604.60	612.45	7.85	
	Five Finger Pattern	612450	619800	FFP42	616.1	612.45	619.80	7.35	
	Five Finger Pattern	619800	627150	FFP43	623.5	619.80	627.15	7.35	
	Five Finger Pattern	627150	634400	FFP44	630.8	627.15	634.40	7.25	
	Five Finger Pattern	634400	641400	FFP45	637.9	634.40	641.40	7.00	
	Five Finger Pattern	641400	648550	FFP46	645.0	641.40	648.55	7.15	
	Five Finger Pattern	648550	655450	FFP47	652.0	648.55	655.45	6.90	
	Five Finger Pattern	655450	662750	FFP48	659.1	655.45	662.75	7.30	
	Five Finger Pattern	662750	669850	FFP49	666.3	662.75	669.85	7.10	
	Five Finger Pattern	669850	676800	FFP50	673.3	669.85	676.80	6.95	
	Five Finger Pattern	676800	683900	FFP51	680.4	676.80	683.90	7.10	
	Five Finger Pattern	683900	690950	FFP52	687.4	683.90	690.95	7.05	
	Five Finger Pattern	690950	698150	FFP53	694.6	690.95	698.15	7.20	
	Five Finger Pattern	698150	705050	FFP54	701.6	698.15	705.05	6.90	
	Five Finger Pattern	705050	711900	FFP55	708.5	705.05	711.90	6.85	

C10101F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	3820	11580	FFP1	7.7	3.82	11.58	7.76	
	Five Finger Pattern	11580	20350	FFP2	16.0	11.58	20.35	8.77	
	Five Finger Pattern	20350	29160	FFP3	24.8	20.35	29.16	8.81	
	Five Finger Pattern	29160	37960	FFP4	33.6	29.16	37.96	8.80	
	Five Finger Pattern	37960	46750	FFP5	42.4	37.96	46.75	8.79	
	Five Finger Pattern	46750	55550	FFP6	51.2	46.75	55.55	8.80	
	Five Finger Pattern	55550	64210	FFP7	59.9	55.55	64.21	8.66	
	Five Finger Pattern	64210	72900	FFP8	68.6	64.21	72.90	8.69	
	Five Finger Pattern	72900	81430	FFP9	77.2	72.90	81.43	8.53	
	Five Finger Pattern	81430	89990	FFP10	85.7	81.43	89.99	8.56	
	Five Finger Pattern	89990	98480	FFP11	94.2	89.99	98.48	8.49	
	Five Finger Pattern	98480	106950	FFP12	102.7	98.48	106.95	8.47	
	Five Finger Pattern	106950	115450	FFP13	111.2	106.95	115.45	8.50	
	Five Finger Pattern	115450	123850	FFP14	119.7	115.45	123.85	8.40	
	Five Finger Pattern	123850	132500	FFP15	128.2	123.85	132.50	8.65	
Fatiguing Exercise 1	isotonic	137900	147400	FEIT1	142.7	137.90	147.40	9.50	
	isometric/isotonic	148200	157700	FEIM1	153.0	148.20	157.70	9.50	
	isotonic	158500	166700	FEIT2	162.6	158.50	166.70	8.20	missed 1 pulse
	isometric/isotonic	167100	177800	FEIM2	172.5	167.10	177.80	10.70	over held
	isotonic	178700	187300	FEIT3	183.0	178.70	187.30	8.60	missed 1 pulse
	isometric/isotonic	187800	197900	FEIM3	192.9	187.80	197.90	10.10	over held
	isotonic	198500	206700	FEIT4	202.6	198.50	206.70	8.20	missed 1 pulse
	isometric/isotonic	207200	217900	FEIM4	212.6	207.20	217.90	10.70	over held
	isotonic	219000	228900	FEIT5	224.0	219.00	228.90	9.90	
	isometric/isotonic	229300	239300	FEIM5	234.3	229.30	239.30	10.00	
	isotonic	239900	249700	FEIT6	244.8	239.90	249.70	9.80	
	isometric/isotonic	250100	259700	FEIM6	254.9	250.10	259.70	9.60	
Piano Exercise 2	Five Finger Pattern	262900	270900	FFP21	266.9	262.90	270.90	8.00	
	Five Finger Pattern	270900	279000	FFP22	275.0	270.90	279.00	8.10	
	Five Finger Pattern	279000	287150	FFP23	283.1	279.00	287.15	8.15	
	Five Finger Pattern	287150	295100	FFP24	291.1	287.15	295.10	7.95	
	Five Finger Pattern	295100	303200	FFP25	299.2	295.10	303.20	8.10	
	Five Finger Pattern	303200	311200	FFP26	307.2	303.20	311.20	8.00	
	Five Finger Pattern	311200	319300	FFP27	315.3	311.20	319.30	8.10	
	Five Finger Pattern	319300	327200	FFP28	323.3	319.30	327.20	7.90	
	Five Finger Pattern	327200	335200	FFP29	331.2	327.20	335.20	8.00	
	Five Finger Pattern	335200	343200	FFP30	339.2	335.20	343.20	8.00	
	Five Finger Pattern	343200	351150	FFP31	347.2	343.20	351.15	7.95	
	Five Finger Pattern	351150	359100	FFP32	355.1	351.15	359.10	7.95	
	Five Finger Pattern	359100	367000	FFP33	363.1	359.10	367.00	7.90	
	Five Finger Pattern	367000	375000	FFP34	371.0	367.00	375.00	8.00	
	Five Finger Pattern	375000	383100	FFP35	379.1	375.00	383.10	8.10	
Fatiguing Exercise 2	isotonic	387600	395400	FEIT21	391.5	387.60	395.40	7.80	missed 1 pulse
	isometric/isotonic	395800	399700	FEIM21	397.8	395.80	399.70	3.90	under held
	isotonic	400300	406100	FEIT22	403.2	400.30	406.10	5.80	missed 4 pulses
	isometric/isotonic	408000	416000	FEIM22	412.0	408.00	416.00	8.00	under held
	isotonic	416300	425800	FEIT23	421.1	416.30	425.80	9.50	
	isometric/isotonic	426200	436200	FEIM23	431.2	426.20	436.20	10.00	
	isotonic	436700	445900	FEIT24	441.3	436.70	445.90	9.20	
	isometric/isotonic	446200	456200	FEIM24	451.2	446.20	456.20	10.00	
	isotonic	456400	466500	FEIT25	461.5	456.40	466.50	10.10	did 1 extra pulse
	isometric/isotonic	466900	476300	FEIM25	471.6	466.90	476.30	9.40	
	isotonic	476900	487400	FEIT26	482.2	476.90	487.40	10.50	missed 1 pulse
	isometric/isotonic	487800	494500	FEIM26	491.2	487.80	494.50	6.70	under held
Piano Exercise 3	Five Finger Pattern	501100	509200	FFP41	505.2	501.10	509.20	8.10	
	Five Finger Pattern	509200	517200	FFP42	513.2	509.20	517.20	8.00	
	Five Finger Pattern	517200	525100	FFP43	521.2	517.20	525.10	7.90	
	Five Finger Pattern	525100	533000	FFP44	529.1	525.10	533.00	7.90	
	Five Finger Pattern	533000	540900	FFP45	537.0	533.00	540.90	7.90	
	Five Finger Pattern	540900	548700	FFP46	544.8	540.90	548.70	7.80	
	Five Finger Pattern	548700	556450	FFP47	552.6	548.70	556.45	7.75	
	Five Finger Pattern	556450	564300	FFP48	560.4	556.45	564.30	7.85	
	Five Finger Pattern	564300	572200	FFP49	568.3	564.30	572.20	7.90	
	Five Finger Pattern	572200	580000	FFP50	576.1	572.20	580.00	7.80	
	Five Finger Pattern	580000	587800	FFP51	583.9	580.00	587.80	7.80	
	Five Finger Pattern	587800	595650	FFP52	591.7	587.80	595.65	7.85	
	Five Finger Pattern	595650	603400	FFP53	599.5	595.65	603.40	7.75	
	Five Finger Pattern	603400	611100	FFP54	607.3	603.40	611.10	7.70	
	Five Finger Pattern	611100	618800	FFP55	615.0	611.10	618.80	7.70	

C10102F	Segment Name	Segment Start	Segment End	Short Form	Midpt Time	Time Start	Time End	Duration	Notes
Piano Exercise 1	Five Finger Pattern	14720	23330	FFP1	19.0	14.72	23.33	8.61	
	Five Finger Pattern	23330	32120	FFP2	27.7	23.33	32.12	8.79	
	Five Finger Pattern	32120	40970	FFP3	36.5	32.12	40.97	8.85	
	Five Finger Pattern	40970	49790	FFP4	45.4	40.97	49.79	8.82	
	Five Finger Pattern	49790	58780	FFP5	54.3	49.79	58.78	8.99	
	Five Finger Pattern	58780	67750	FFP6	63.3	58.78	67.75	8.97	
	Five Finger Pattern	67750	76890	FFP7	72.3	67.75	76.89	9.14	
	Five Finger Pattern	76890	85670	FFP8	81.3	76.89	85.67	8.78	
	Five Finger Pattern	85670	94630	FFP9	90.2	85.67	94.63	8.96	
	Five Finger Pattern	94630	103600	FFP10	99.1	94.63	103.60	8.97	
	Five Finger Pattern	103600	113600	FFP11	108.6	103.60	113.60	10.00	
	Five Finger Pattern	113600	122500	FFP12	118.1	113.60	122.50	8.90	
	Five Finger Pattern	122500	131400	FFP13	127.0	122.50	131.40	8.90	
	Five Finger Pattern	131400	140400	FFP14	135.9	131.40	140.40	9.00	
	Five Finger Pattern	140400	149200	FFP15	144.8	140.40	149.20	8.80	
Fatiguing Exercise 1	isotonic	152500	162200	FEIT1	157.4	152.50	162.20	9.70	
	isometric/isotonic	162800	172000	FEIM1	167.4	162.80	172.00	9.20	
	isotonic	172600	182100	FEIT2	177.4	172.60	182.10	9.50	
	isometric/isotonic	182700	190100	FEIM2	186.4	182.70	190.10	7.40	under held
	isotonic	192800	202300	FEIT3	197.6	192.80	202.30	9.50	
	isometric/isotonic	202800	212300	FEIM3	207.6	202.80	212.30	9.50	
	isotonic	212800	222300	FEIT4	217.6	212.80	222.30	9.50	
	isometric/isotonic	222700	232500	FEIM4	227.6	222.70	232.50	9.80	
	isotonic	232900	242300	FEIT5	237.6	232.90	242.30	9.40	
	isometric/isotonic	242800	252800	FEIM5	247.8	242.80	252.80	10.00	missed 1 full IT and IM segment
Piano Exercise 2	Five Finger Pattern	255900	264450	FFP21	260.2	255.90	264.45	8.55	
	Five Finger Pattern	264450	273000	FFP22	268.7	264.45	273.00	8.55	
	Five Finger Pattern	273000	281600	FFP23	277.3	273.00	281.60	8.60	
	Five Finger Pattern	281600	290300	FFP24	286.0	281.60	290.30	8.70	
	Five Finger Pattern	290300	298800	FFP25	294.6	290.30	298.80	8.50	
	Five Finger Pattern	298800	307650	FFP26	303.2	298.80	307.65	8.85	
	Five Finger Pattern	307650	316200	FFP27	311.9	307.65	316.20	8.55	
	Five Finger Pattern	316200	324950	FFP28	320.6	316.20	324.95	8.75	
	Five Finger Pattern	324950	333900	FFP29	329.4	324.95	333.90	8.95	
	Five Finger Pattern	333900	342550	FFP30	338.2	333.90	342.55	8.65	
	Five Finger Pattern	342550	351050	FFP31	346.8	342.55	351.05	8.50	
	Five Finger Pattern	351050	359700	FFP32	355.4	351.05	359.70	8.65	
	Five Finger Pattern	359700	368400	FFP33	364.1	359.70	368.40	8.70	
	Five Finger Pattern	368400	377100	FFP34	372.8	368.40	377.10	8.70	
	Five Finger Pattern	377100	385700	FFP35	381.4	377.10	385.70	8.60	
Fatiguing Exercise 2	isotonic	390500	397100	FEIT21	393.8	390.50	397.10	6.60	missed 3 pulses
	isometric/isotonic	397400	407400	FEIM21	402.4	397.40	407.40	10.00	
	isotonic	407800	417300	FEIT22	412.6	407.80	417.30	9.50	
	isometric/isotonic	417600	427500	FEIM22	422.6	417.60	427.50	9.90	
	isotonic	427900	437200	FEIT23	432.6	427.90	437.20	9.30	
	isometric/isotonic	437500	447400	FEIM23	442.5	437.50	447.40	9.90	
	isotonic	447800	457500	FEIT24	452.7	447.80	457.50	9.70	
	isometric/isotonic	458100	467300	FEIM24	462.7	458.10	467.30	9.20	
	isotonic	467800	477400	FEIT25	472.6	467.80	477.40	9.60	
	isometric/isotonic	477900	487700	FEIM25	482.8	477.90	487.70	9.80	
	isotonic	488100	497600	FEIT26	492.9	488.10	497.60	9.50	
	isometric/isotonic	498100	507900	FEIM26	503.0	498.10	507.90	9.80	
Piano Exercise 3	Five Finger Pattern	510900	519050	FFP41	515.0	510.90	519.05	8.15	
	Five Finger Pattern	519050	527250	FFP42	523.2	519.05	527.25	8.20	
	Five Finger Pattern	527250	535450	FFP43	531.4	527.25	535.45	8.20	
	Five Finger Pattern	535450	543550	FFP44	539.5	535.45	543.55	8.10	
	Five Finger Pattern	543550	551850	FFP45	547.7	543.55	551.85	8.30	
	Five Finger Pattern	551850	560000	FFP46	555.9	551.85	560.00	8.15	
	Five Finger Pattern	560000	568550	FFP47	564.3	560.00	568.55	8.55	
	Five Finger Pattern	568550	576900	FFP48	572.7	568.55	576.90	8.35	
	Five Finger Pattern	576900	585100	FFP49	581.0	576.90	585.10	8.20	
	Five Finger Pattern	585100	593200	FFP50	589.2	585.10	593.20	8.10	
	Five Finger Pattern	593200	601150	FFP51	597.2	593.20	601.15	7.95	
	Five Finger Pattern	601150	609450	FFP52	605.3	601.15	609.45	8.30	
	Five Finger Pattern	609450	617800	FFP53	613.6	609.45	617.80	8.35	
	Five Finger Pattern	617800	626200	FFP54	622.0	617.80	626.20	8.40	
	Five Finger Pattern	626200	634700	FFP55	630.5	626.20	634.70	8.50	

Appendix F

Each Participant's MDF Values

P9052F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	36.5	92.1297	127.7688	84.4574	99.8020
	FFP2	65.7	95.6917	130.6811	80.7496	104.6570
	FFP3	77.7	93.5508	126.1717	80.3025	99.3001
	FFP4	106.8	94.3906	119.5447	79.4240	100.8049
	FFP5	118.9	95.8005	129.6713	86.8016	99.0501
	FFP6	148.1	96.0750	123.0282	90.1130	102.5338
Fatiguing Exercise 1	FEIT1	163.6	96.5004	121.8102	78.5856	97.5419
	FEIM1	174.0	112.7831	124.1545	87.6875	104.2545
	FEIT2	184.0	95.4198	110.6870	76.6047	89.2915
	FEIM2	193.9	106.8447	117.3590	77.9817	103.5460
	FEIT3	203.3	91.4598	112.8691	75.2264	96.5181
	FEIM3	213.4	112.6780	110.6971	82.2092	106.5466
	FEIT4	223.4	94.1654	111.4575	70.7564	89.2248
	FEIM4	233.4	105.5089	112.4894	78.1530	94.7552
	FEIT5	243.5	90.5068	107.5164	75.5660	87.9784
	FEIM5	253.5	100.1321	113.2440	83.7185	93.3403
	FEIT6	264.0	83.7934	113.3736	70.7739	91.7092
	FEIM6	274.7	97.2014	104.6977	86.2069	95.2024
Piano Exercise 2	FFP21	289.6	91.4261	119.6725	82.1772	101.9248
	FFP22	325.9	96.1755	130.1712	85.4268	100.9249
	FFP23	338.0	93.8008	134.2957	87.4266	106.6742
	FFP24	367.1	99.8000	137.5453	89.0514	102.5497
	FFP25	379.2	95.0506	132.5459	92.1760	105.6743
	FFP26	408.3	93.4667	129.4870	82.9090	107.0053
Fatiguing Exercise 2	FEIT21	425.0	98.2528	115.7247	74.9921	87.6224
	FEIM21	434.9	118.5814	139.8292	98.5835	89.3136
	FEIT22	444.9	90.5755	113.0199	73.2369	87.1716
	FEIM22	455.0	110.3459	124.6301	89.0215	90.6540
	FEIT23	464.6	88.9895	113.9278	77.9320	87.8132
	FEIM23	474.6	108.2278	122.8931	90.1343	91.6579
	FEIT24	485.2	86.1024	103.4744	72.9724	86.9104
	FEIM24	494.4	102.3197	109.3854	76.5898	91.7878
	FEIM24b	503.2	101.5895	119.0232	89.2834	92.1036
	FEIT25	512.3	85.0432	103.5830	72.2321	87.5430
	FEIM25	522.5	101.5713	100.1428	75.7576	87.3890
	FEIT26	532.5	86.1735	103.3760	71.7665	84.5608
	FEIM26	542.6	97.6402	108.5391	77.0423	91.7408
	FEIT27	552.6	81.0853	100.2500	70.2531	81.9186
	FEIM27	562.6	87.3347	112.4362	75.6692	89.2095
Piano Exercise 3	FFP31	577.0	86.4267	127.7965	80.8024	95.0506
	FFP32	606.3	90.0506	123.5033	93.2601	105.1105
	FFP33	618.4	90.1785	124.3513	86.3815	92.9629
	FFP34	647.5	97.0868	132.6379	87.0880	97.7040
	FFP35	659.5	91.1761	135.0456	84.4269	97.8003
	FFP36	688.7	96.7599	128.1483	88.2800	97.1396

P9191F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	9.6	80.2469	108.6053	78.0467	102.2491
	FFP2	38.7	82.1113	108.2899	89.6255	96.0490
	FFP3	50.8	82.6227	107.2179	81.5103	91.5214
	FFP4	80.0	88.9264	106.4242	93.5508	90.3012
	FFP5	91.9	91.0734	105.4108	87.0839	86.7099
	FFP6	120.8	85.8177	108.3916	94.1602	97.7181
Fatiguing Exercise 1	FEIT1	141.1	93.2938	95.8936	99.4267	105.2930
	FEIM1	153.9	96.2373	94.7902	95.8427	89.0014
	FEIT2	163.1	77.0347	84.8833	95.6349	98.7528
	FEIM2	173.1	83.3419	91.0731	83.4450	86.5375
	FEIT3	183.0	74.0680	87.2188	94.1745	92.4356
	FEIM3	192.8	76.5709	85.2016	73.3081	94.0427
	FEIT4	203.0	67.2801	78.5555	88.9799	89.8309
	FEIM4	213.0	66.9830	85.9606	64.1261	89.5317
	FEIT5	223.1	63.5953	78.8625	91.7643	93.0545
	FEIM5	233.1	72.0029	84.8882	60.3546	80.5587
	FEIT6	243.1	66.3614	77.8339	98.9896	94.0427
	FEIM6	253.2	70.6561	85.5525	65.5545	87.5931
	FEIT7	263.3	62.1128	78.9588	88.4143	87.3275
	FEIM7	273.3	66.6769	81.7774	63.0038	90.7560
Piano Exercise 2	FFP21	286.9	75.9533	95.7024	92.5972	99.5529
	FFP22	316.0	81.3023	98.3002	83.5521	95.0506
	FFP23	328.1	89.4263	103.1746	89.5513	97.1754
	FFP24	357.2	85.2624	106.3507	101.1393	94.3522
	FFP25	369.3	78.9276	100.1750	92.9259	106.9241
	FFP26	398.5	90.3614	104.5212	88.4983	99.5529
Fatiguing Exercise 2	FEIT21	414.2	91.8436	94.4276	94.9893	99.3709
	FEIM21	423.9	97.5419	99.9375	102.4372	104.7287
	FEIT22	433.9	81.5844	85.9796	91.0340	93.5611
	FEIM22	443.9	93.8406	97.1403	74.0426	93.6406
	FEIT23	454.2	84.5123	89.5118	96.0004	98.3406
	FEIM23	464.1	80.8862	87.7276	69.0980	91.9377
	FEIT24	474.0	75.8708	79.3869	79.6066	77.0794
	FEIM24	484.0	85.6414	90.3410	66.6433	84.9415
	FEIT25	494.1	73.3436	78.0683	90.3747	99.9341
	FEIM25	504.2	71.0534	83.8804	64.6904	84.1834
	FEIT26	514.2	71.0361	78.6177	85.1005	98.9452
	FEIM26	524.2	73.3764	79.7394	64.6904	87.6174
Piano Exercise 3	FFP31	536.1	73.7563	94.4945	97.9509	101.2838
	FFP32	565.1	84.6006	100.2874	94.3001	108.1906
	FFP33	577.3	87.6289	102.5338	86.7594	102.4096
	FFP34	606.5	79.6775	101.7998	89.4263	100.1750
	FFP35	618.5	87.4266	104.5494	88.9264	99.1751
	FFP36	647.7	89.9888	105.5148	92.1004	97.0687

P9192F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	9.5	97.6753	X	98.4252	100.9249
	FFP2	38.6	98.6752	X	102.0497	117.0479
	FFP3	50.7	89.9514	X	93.1929	112.2678
	FFP4	79.8	91.1177	X	89.3810	113.6956
	FFP5	91.9	94.6757	X	93.0509	105.2993
	FFP6	121.0	95.9255	X	98.9251	113.4233
Fatiguing Exercise 1	FEIT1	136.9	98.8091	X	79.7101	81.0583
	FEIM1	146.5	110.5614	X	81.0853	95.9796
	FEIT2	156.6	98.7918	X	76.9191	81.1895
	FEIM2	166.8	99.8351	X	78.2909	92.2070
	FEIT3	176.7	96.9170	X	77.7523	77.3357
	FEIM3	186.7	102.7497	X	72.4404	87.2305
	FEIT4	196.8	83.9385	X	77.9392	80.9915
	FEIM4	207.1	97.7626	X	82.8136	98.2576
	FEIT5	217.1	88.4314	X	80.0452	83.3781
	FEIM5	227.0	92.9286	X	71.2813	84.7851
	FEIT6	237.1	85.3134	X	73.8093	87.8938
	FEIM6	247.1	80.7096	X	104.1979	121.1894
Piano Exercise 2	FFP21	262.7	92.8009	X	89.9263	91.8010
	FFP22	291.8	87.3016	X	103.0496	115.5481
	FFP23	303.9	99.1751	X	95.4256	109.9238
	FFP24	333.1	93.6304	X	95.1117	116.2202
	FFP25	345.1	96.3005	X	101.4248	110.0487
	FFP26	374.2	95.0506	X	98.1752	130.5462
Fatiguing Exercise 2	FEIT21	389.9	109.3043	X	80.3600	81.4125
	FEIM21	399.8	120.6859	X	90.9042	93.5921
	FEIT22	409.9	107.5662	X	86.0221	91.6916
	FEIM22	419.9	118.0402	X	104.0417	100.3579
	FEIT23	429.9	106.8118	X	83.6892	81.6061
	FEIM23	440.0	115.6194	X	84.3595	99.6211
	FEIT24	450.0	105.9785	X	76.3983	82.8560
	FEIM24	460.0	111.8498	X	83.4486	82.2785
	FEIT25	470.1	96.5004	X	74.3152	88.1679
	FEIM25	480.2	113.5819	X	79.9396	91.9175
	FEIT26	490.2	102.7497	X	79.4188	86.5014
	FEIM26	500.3	110.8739	X	80.2521	83.7934
	FEIT27	510.3	96.8845	X	70.6768	87.2013
	FEIM27	520.3	103.5830	X	83.3767	91.5009
	FEIT28	530.4	100.0417	X	74.1069	86.1889
	FEIM28	540.5	106.3572	X	80.5705	79.8337
	FEIT29	550.0	95.2189	X	67.7508	84.1857
	FEIM29	560.1	95.8480	X	72.8978	95.9432
	FEIT30	570.6	96.8128	X	73.5861	88.2721
	FEIM30	580.7	106.7076	X	86.5014	100.1458
	FEIT31	590.7	93.7270	X	66.6772	81.7282
	FEIM31	600.7	102.7018	X	81.4275	100.2553
Piano Exercise 3	FFP31	612.4	92.4259	X	101.1749	110.4237
	FFP32	648.6	98.6834	X	94.7087	130.6049
	FFP33	660.6	103.2791	X	91.9762	122.5314
	FFP34	689.8	102.1479	X	103.1354	130.6629
	FFP35	701.8	99.0501	X	101.2998	124.4219
	FFP36	731.0	100.7949	X	102.5338	132.2196

P9193M	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	11.4	62.6480	74.3673	119.8728	104.2887
	FFP2	44.6	66.1846	71.8700	117.4762	91.5214
	FFP3	56.6	68.1228	74.6814	115.5179	100.5445
	FFP4	85.8	71.0011	79.3542	117.3794	93.4422
	FFP5	97.8	70.1526	80.5731	123.4958	97.6926
	FFP6	126.9	68.5539	76.5529	115.5481	102.5497
Fatiguing Exercise 1	FEIT1	143.8	66.6495	94.2210	107.4553	80.1779
	FEIM1	156.1	62.6854	88.9463	94.3303	84.6610
	FEIT2	166.6	63.6856	89.1973	113.4006	81.1606
	FEIM2	177.2	67.8731	87.9796	96.2395	81.7846
	FEIT3	187.4	69.1344	94.5864	102.2624	82.4664
	FEIM3	198.0	78.3620	89.1473	99.4832	78.6990
	FEIT4	207.9	68.2892	96.1982	111.1416	80.1560
	FEIM4	218.0	78.2596	94.4956	74.0026	78.6556
	FEIT5	228.0	77.4910	93.3031	106.9062	86.9085
	FEIM5	238.0	76.6430	95.9616	83.2443	77.6138
	FEIT6	248.0	73.3443	94.9888	97.8120	80.4023
	FEIM6	257.8	74.7015	92.4668	67.2265	80.5262
	FEIT7	268.1	76.9909	97.9297	110.5164	81.6963
	FEIM7	278.2	71.9092	90.4121	61.8167	71.2550
Piano Exercise 2	FFP21	292.8	61.0418	72.1516	121.0344	113.0107
	FFP22	321.9	69.4288	76.6779	119.7975	97.6753
	FFP23	333.9	65.2714	78.0648	116.9420	90.8583
	FFP24	363.1	66.1030	78.2002	123.9970	95.1117
	FFP25	375.1	70.8036	81.4273	119.9225	99.6750
	FFP26	404.2	66.8469	80.8074	125.0786	90.2402
Fatiguing Exercise 2	FEIT21	419.8	75.6692	93.5840	113.4778	80.6687
	FEIM21	429.9	85.3484	100.0408	97.2860	78.0022
	FEIT22	440.4	75.3567	99.2084	115.6650	79.7313
	FEIM22	450.1	75.2526	97.9585	91.8134	80.7728
	FEIT23	460.4	74.4193	98.6876	117.3315	83.1684
	FEIM23	470.5	73.4133	97.0950	89.2011	81.7282
	FEIT24	480.1	77.3509	101.6178	111.3920	73.9805
	FEIM24	490.0	74.7524	90.8086	94.6544	84.4630
	FEIT25	500.2	76.2556	101.6550	98.6668	82.8066
	FEIM25	510.2	74.1911	92.7743	67.9653	77.3040
	FEIT26	520.4	72.5779	94.9891	102.4595	80.7378
	FEIM26	530.2	76.9726	100.9306	90.1396	82.9126
	FEIT27	540.4	78.7979	108.7945	97.8866	84.7063
	FEIM27	550.3	77.8700	102.3960	79.6623	81.4546
	FEIT28	560.5	71.0964	101.0929	90.6290	83.5368
	FEIM28	568.5	64.3747	97.9080	83.2949	80.0646
	FEIT29	578.0	69.0112	88.4967	92.2571	81.8306
	FEIM29	589.1	65.9627	88.7154	70.2479	84.7363
	FEIT30	599.1	67.3367	86.2931	93.1674	81.2936
	FEIM30	609.1	65.2906	85.5856	70.5376	82.7146
	FEIT31	618.8	74.1193	89.4663	95.6284	84.8157
	FEIM31	628.8	74.9929	84.3253	74.2310	78.8020
	FEIT32	638.8	74.1193	98.7676	84.2344	81.3278
	FEIM32	648.9	68.2807	101.7035	63.4663	65.5032
Piano Exercise 3	FFP31	663.6	64.2513	75.8548	123.2564	111.4060
	FFP32	692.7	72.6454	83.0144	129.7988	105.4808
	FFP33	704.7	72.8481	85.7657	123.0282	106.8811
	FFP34	740.9	69.6187	86.3868	120.1714	100.0497
	FFP35	753.0	74.6782	95.9255	120.9224	102.9145
	FFP36	782.1	72.8481	93.0940	121.7861	90.9825

P9231F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	9.4	94.1611	126.6132	64.3403	88.0216
	FFP2	38.5	90.3012	124.0470	73.3033	88.4264
	FFP3	50.6	91.3830	118.6409	73.1692	89.4988
	FFP4	79.7	96.4165	126.9891	73.3617	88.3974
	FFP5	91.8	90.7316	117.8063	68.1904	88.2131
	FFP6	120.9	96.0505	124.6719	71.6785	87.1766
Fatiguing Exercise 1	FEIT1	138.4	96.2657	102.7956	75.0434	81.6753
	FEIM1	148.5	100.5624	112.6445	77.1274	90.4593
	FEIT2	159.0	93.4798	97.0211	69.5240	80.3562
	FEIM2	168.8	102.7108	109.5989	78.3802	97.0448
	FEIT3	178.6	91.4264	107.1695	76.2153	86.5333
	FEIM3	188.6	101.4104	106.9887	77.0971	98.8843
	FEIT4	198.7	97.3880	104.2241	76.6758	81.1652
	FEIM4	208.6	108.8593	107.5691	71.3364	91.1192
	FEIT5	218.7	97.1840	96.3677	71.0642	80.7571
	FEIM5	228.8	101.3957	106.2910	61.6082	89.8344
	FEIT6	238.9	96.5364	98.4950	71.8998	87.2590
	FEIM6	249.4	104.1329	102.1331	67.4698	88.3249
Piano Exercise 2	FFP21	262.6	82.7847	108.7443	68.9976	91.9762
	FFP22	291.7	89.1083	129.3548	68.7335	87.5990
	FFP23	303.8	91.4261	123.1721	66.0542	86.9266
	FFP24	332.9	88.1765	125.1719	69.3038	90.3012
	FFP25	345.0	86.9266	125.7968	70.0537	92.8009
	FFP26	374.1	88.5514	124.1720	74.5532	91.6760
Fatiguing Exercise 2	FEIT21	388.5	101.4692	109.0195	79.0225	79.4307
	FEIM21	398.7	112.0408	113.0934	80.7810	92.0429
	FEIT22	408.7	98.7918	104.1037	80.4604	85.6682
	FEIM22	418.7	109.1990	110.9883	81.6230	92.6745
	FEIT23	428.8	93.7532	106.5354	76.4354	81.8988
	FEIM23	438.8	110.1463	107.0940	77.5182	81.8335
	FEIT24	448.8	95.9796	102.5414	75.7734	82.4393
	FEIM24	459.0	113.4419	114.5758	87.9806	87.8775
	FEIT25	469.0	99.9382	109.3186	77.5693	82.9296
	FEIM25	478.9	115.8919	114.4027	78.6618	86.6397
	FEIT26	489.1	99.3197	103.5460	77.1570	76.9508
	FEIM26	499.1	114.7332	114.3251	86.4708	92.6946
	FEIT27	509.2	97.3611	101.3813	80.6618	83.8573
	FEIM27	519.2	117.3590	112.1018	84.3727	90.8669
	FEIT28	529.3	100.0408	99.2246	79.1246	80.3489
	FEIM28	539.4	117.0929	112.2513	83.5175	103.3049
	FEIT29	549.3	100.9690	103.8553	80.8680	86.3313
	FEIM29	559.5	109.9384	108.7264	85.1934	93.6774
Piano Exercise 3	FFP31	573.2	86.6346	120.3012	81.8251	95.3677
	FFP32	602.2	87.9265	121.7973	73.0534	92.0510
	FFP33	614.3	87.8015	117.4228	77.1779	88.0515
	FFP34	643.4	92.0510	122.5472	74.6782	89.8013
	FFP35	655.5	87.1766	127.2966	74.9281	89.9263
	FFP36	684.7	86.7177	122.6392	70.7937	94.2476

P9291F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	23.3	78.9938	120.4766	103.9591	117.3244
	FFP2	52.6	77.7894	116.8468	109.5560	123.0960
	FFP3	63.4	83.3768	118.5011	111.5458	121.2833
	FFP4	101.5	81.1834	117.6357	108.1376	121.8714
	FFP5	113.7	75.8291	121.2893	104.8938	118.3083
	FFP6	142.1	78.4865	113.2532	102.7970	123.3172
Fatiguing Exercise 1	FEIT1	160.8	94.7180	100.3695	102.4345	75.3722
	FEIM1	170.8	106.1776	106.4746	83.8036	73.5076
	FEIT2	180.8	93.9146	99.3979	94.8823	69.7237
	FEIM2	190.5	97.4626	101.8708	74.8844	70.1537
	FEIT3	200.5	87.1263	97.0211	88.7928	72.3362
	FEIM3	210.5	89.4297	87.2870	74.6352	70.2479
	FEIT4	220.7	91.6408	98.9401	85.8414	68.5431
	FEIM4	230.8	83.8082	82.6255	68.6485	68.0034
	FEIT5	240.7	80.6550	88.3073	78.2063	68.9215
	FEIM5	250.8	92.6946	95.1434	57.9023	62.5957
	FEIT6	260.9	85.7994	91.4554	75.9014	67.1144
	FEIM6	271.1	89.7461	87.7855	71.2185	64.5525
Piano Exercise 2	FFP21	289.6	61.7745	99.1265	110.6195	124.6408
	FFP22	325.8	66.8095	107.7133	109.5312	127.0614
	FFP23	337.7	70.7101	112.0225	105.4365	125.0748
	FFP24	366.7	73.1355	112.6273	106.7161	126.5879
	FFP25	379.0	73.1391	111.8998	108.9372	117.5781
	FFP26	407.5	86.0400	121.5769	107.8207	127.1813
Fatiguing Exercise 2	FEIT21	421.8	126.0617	106.0639	96.9251	72.1965
	FEIM21	431.7	140.8618	100.7628	83.8573	67.9827
	FEIT22	441.8	110.8560	104.2241	86.1647	72.9007
	FEIM22	451.8	113.3390	109.4033	80.1510	69.6203
	FEIT23	461.9	102.8245	100.5566	83.4450	69.4258
	FEIM23	471.9	107.8077	95.8941	83.4486	68.9820
	FEIT24	481.9	100.7628	90.0423	81.8988	71.1782
	FEIM24	491.9	103.8954	98.7918	75.6692	62.3373
	FEIT25	502.1	99.3197	101.9998	77.8786	72.4152
	FEIM25	512.1	107.0809	98.6124	75.9616	61.8814
	FEIT26	522.2	101.5156	92.5692	79.0969	70.0453
	FEIM26	532.2	98.0596	87.8626	67.7656	63.2116
	FEIT27	542.3	91.2792	87.4652	75.3015	68.2919
	FEIM27	552.1	96.6377	87.2981	66.9707	53.1260
Piano Exercise 3	FFP31	565.7	60.6553	100.4096	106.6739	120.6481
	FFP32	593.9	73.9119	107.8944	105.2804	130.2444
	FFP33	605.8	70.9178	114.8854	102.0395	127.7314
	FFP34	639.3	69.8564	106.7642	111.5958	126.0905
	FFP35	651.2	75.2133	108.4575	112.4061	128.3276
	FFP36	678.1	74.4567	112.3184	110.7186	124.1834

P1031F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	63.6	69.5538	92.6759	90.3012	62.6797
	FFP2	92.2	72.5287	89.1933	89.3195	68.9938
	FFP3	103.9	71.7595	88.2209	92.0010	64.4434
	FFP4	133.0	68.8734	89.7404	85.3931	67.0103
	FFP5	145.1	74.6447	89.1083	89.4856	65.8408
	FFP6	174.2	69.3703	89.8646	90.1130	67.2587
Fatiguing Exercise 1	FEIT1	188.8	65.2964	63.6804	75.1944	51.7624
	FEIM1	199.1	69.4374	71.5584	70.2454	77.0124
	FEIT2	209.2	64.9372	58.6046	62.6042	56.0493
	FEIM2	219.2	71.9624	63.3774	69.6394	33.1785
	FEIT3	229.2	65.6994	56.6786	57.6568	38.8545
	FEIM3	239.3	80.1434	66.6094	75.2954	67.2154
	FEIT4	249.3	67.5734	56.0692	54.0264	59.1872
	FEIM4	259.3	74.5884	62.8724	69.0334	64.5894
	FEIT5	269.3	58.7571	53.9189	55.1016	54.9941
	FEIM5	279.6	80.2349	65.5762	69.4593	64.3141
	FEIT6	289.6	63.7569	53.8704	51.6234	58.5889
	FEIM6	299.6	78.9828	64.4650	58.7924	58.8886
Piano Exercise 2	FFP21	310.9	66.8861	72.2271	83.4058	67.0103
	FFP22	340.0	67.8531	79.8013	89.6114	43.4537
	FFP23	352.1	71.6785	83.5521	92.3010	65.0544
	FFP24	381.2	71.3576	86.1384	86.0142	65.6440
	FFP25	393.3	70.8036	89.6763	84.8019	57.1804
	FFP26	422.4	75.3611	92.8898	85.8536	68.2015
Fatiguing Exercise 2	FEIT21	438.9	76.8197	64.0254	62.5202	54.4565
	FEIM21	448.9	84.8858	74.0448	66.8877	75.0974
	FEIT22	459.1	74.7861	65.7149	57.5714	59.7361
	FEIM22	469.2	87.3066	67.9402	65.7299	65.4142
	FEIT23	479.2	67.3367	59.8375	50.9843	64.3162
	FEIM23	489.2	83.6892	67.3367	62.1289	70.6697
	FEIT24	499.2	70.8780	57.3378	48.6928	62.4414
	FEIM24	509.4	83.2417	69.7430	62.4438	54.3446
	FEIT25	519.4	69.3011	58.6640	51.7498	61.4296
	FEIM25	529.5	79.1156	66.5395	62.7255	58.4991
	FEIT26	539.5	73.2028	60.2568	50.6789	60.4673
	FEIM26	549.3	80.1510	72.2795	57.8130	61.1105
Piano Exercise 3	FFP31	561.1	67.0541	76.0530	84.9269	72.9284
	FFP32	590.2	70.1787	76.1780	89.6763	65.8043
	FFP33	603.3	69.2950	79.0406	90.6847	70.1810
	FFP34	632.4	69.6788	84.3020	87.9265	62.5547
	FFP35	644.5	73.8798	87.5818	97.7040	64.1279
	FFP36	673.6	74.1983	89.6842	96.3907	72.0034

P1032F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	8.1	100.7939	128.3340	107.6169	127.4656
	FFP2	37.3	98.3023	124.7659	102.9210	131.8812
	FFP3	49.4	100.5458	130.3188	102.1585	128.0858
	FFP4	78.5	97.9330	126.8211	109.2641	131.6773
	FFP5	89.5	98.8120	128.7588	104.3806	123.4377
	FFP6	118.7	101.1749	127.6715	109.5488	128.5464
Fatiguing Exercise 1	FEIT1	134.3	97.8544	116.8107	93.7923	110.4572
	FEIM1	144.5	120.3634	118.1056	87.8938	117.1379
	FEIT2	154.4	92.0869	104.8812	91.3343	113.0524
	FEIM2	164.4	104.3574	122.4608	69.7295	94.1480
	FEIT3	174.5	91.2009	101.7261	74.9921	108.7780
	FEIM3	184.5	105.5152	119.0927	67.2035	94.5690
	FEIT4	194.8	96.3482	112.2161	81.2412	103.7387
	FEIM4	204.5	104.5204	120.7687	72.4404	96.9170
	FEIT5	214.7	91.2137	110.6797	73.1305	108.0204
	FEIM5	224.7	103.2705	119.1022	64.8370	96.8128
	FEIT6	234.7	80.5645	110.6656	72.9611	102.5414
	FEIM6	245.1	98.7768	120.5223	69.7505	100.2330
Piano Exercise 2	FFP21	260.3	87.5516	123.2971	112.9234	136.6704
	FFP22	289.5	90.8011	119.4226	109.5488	125.7968
	FFP23	300.6	99.1853	120.0469	113.0107	133.6255
	FFP24	329.7	92.5972	126.6302	111.4768	123.8977
	FFP25	341.8	101.5307	125.8487	109.3075	134.1192
	FFP26	370.9	96.0505	120.1725	116.6729	138.9201
Fatiguing Exercise 2	FEIT21	385.7	106.1117	115.9982	108.9203	120.3797
	FEIM21	395.4	114.1027	125.2474	85.1474	102.5414
	FEIT22	405.7	102.6810	114.7676	88.5068	116.4158
	FEIM22	415.4	116.6004	130.1473	85.6360	108.9668
	FEIT23	425.6	99.6211	111.1988	78.3602	111.6198
	FEIM23	435.5	106.7076	120.6645	73.1695	106.9159
	FEIT24	445.6	96.5004	118.6856	77.2315	108.4783
	FEIM24	455.6	113.9985	118.6856	72.2321	105.4578
	FEIT25	465.8	98.4950	113.4419	66.8488	107.0508
	FEIM25	475.8	112.3817	133.8687	72.5987	103.0210
	FEIT26	485.9	98.1669	118.6856	70.0448	104.8328
	FEIM26	496.0	106.4323	139.5217	61.9008	95.0933
Piano Exercise 3	FFP31	508.5	97.4413	126.6302	113.5884	132.3438
	FFP32	537.7	100.9249	126.7967	103.2996	134.5457
	FFP33	551.8	96.0992	122.3923	111.8998	128.5644
	FFP34	580.9	94.5507	121.0474	115.9230	129.2963
	FFP35	591.0	93.4258	124.4219	112.4234	130.6712
	FFP36	620.1	90.8011	126.7967	117.6728	133.2958

P1071F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	8.3	85.4833	105.1105	106.2215	102.6416
	FFP2	37.4	97.6869	115.4707	99.9254	97.4381
	FFP3	49.5	96.5418	112.5799	96.9177	96.0406
	FFP4	78.6	92.7663	110.2950	92.5194	95.2352
	FFP5	90.7	96.1659	106.6909	85.2650	95.5394
	FFP6	119.8	94.9274	99.3172	65.4189	99.1952
Fatiguing Exercise 1	FEIT1	137.1	95.6576	103.7520	64.7081	114.9890
	FEIM1	148.2	105.1029	106.2522	76.3705	88.2083
	FEIT2	158.2	86.7803	86.8856	79.5179	107.4097
	FEIM2	168.1	92.1710	89.6181	80.7893	78.7682
	FEIT3	178.0	81.5177	81.4125	90.4642	109.5148
	FEIM3	188.0	97.3055	94.3585	86.7803	84.6753
	FEIT4	198.1	82.7977	83.6139	84.1241	113.2027
	FEIM4	208.3	88.0637	86.1889	89.4178	79.9396
	FEIT5	218.3	83.1684	85.1474	83.7934	102.4372
	FEIM5	228.3	91.0843	89.3136	90.2510	78.8980
	FEIT6	238.3	84.8349	87.0222	83.2726	113.0611
	FEIM6	248.4	90.8852	90.6747	74.7816	78.4654
Piano Exercise 2	FFP21	262.5	84.7426	88.4459	100.1728	91.5319
	FFP22	291.6	89.3013	94.3007	96.0505	100.1750
	FFP23	303.7	90.5512	97.8003	100.1750	95.0506
	FFP24	332.8	84.1770	101.7998	106.6742	91.5511
	FFP25	344.9	87.8015	106.7992	98.0502	94.0507
	FFP26	374.1	87.2115	100.2963	107.5793	94.2476
	FFP27	386.2	90.9379	103.0882	104.9867	90.8113
	FFP28	415.3	94.0007	106.4683	103.0120	91.4085
Fatiguing Exercise 2	FEIT21	430.7	90.6540	100.5510	99.1225	116.0596
	FEIM21	440.8	102.8539	108.1658	97.1253	83.6892
	FEIT22	450.9	91.3823	99.7320	89.6299	121.1731
	FEIM22	460.9	92.0429	101.3051	89.0959	87.3066
	FEIT23	470.9	83.9604	92.5162	85.3005	121.2762
	FEIM23	480.9	87.8554	96.5004	82.3352	83.8975
	FEIT24	491.1	81.8988	92.6193	86.1251	111.8957
	FEIM24	501.1	88.2539	93.5165	85.4121	82.7808
	FEIT25	511.1	83.0417	89.6410	86.5413	116.6383
	FEIM25	521.2	93.0955	94.4637	83.9385	83.0965
	FEIT26	531.1	77.6234	84.9911	81.2020	105.3047
	FEIM26	541.2	87.4911	88.0012	77.6962	83.1038
	FEIT27	551.3	80.3562	89.9385	79.2105	110.2489
	FEIM27	561.3	86.0848	90.3552	85.2515	79.9396
	FEIT28	571.4	86.7769	89.6337	83.5119	104.5301
	FEIM28	581.5	88.3073	93.3068	87.7972	81.6753
	FEIT29	591.6	79.1156	85.5066	78.2909	109.8340
	FEIM29	601.6	83.0643	84.2100	73.7944	71.1905
Piano Exercise 3	FFP31	613.2	84.6769	93.3008	100.4249	93.4258
	FFP32	642.3	85.9268	99.8000	101.9248	100.1750
	FFP33	654.5	87.1409	104.2273	98.0256	98.7850
	FFP34	683.6	88.8162	102.3948	105.3574	87.4583
	FFP35	695.6	87.8015	107.9240	100.5499	100.7999
	FFP36	724.8	89.6803	106.8387	109.5544	97.5805

P1072F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	8.3	94.4394	116.1076	99.6606	74.0765
	FFP2	35.7	97.4078	119.2303	91.9852	79.4207
	FFP3	45.6	84.8956	114.1471	90.4800	74.9235
	FFP4	72.2	87.5554	121.1531	86.8835	76.9386
	FFP5	83.2	93.3067	118.6476	89.1750	68.7922
	FFP6	109.1	96.1936	111.3639	91.2288	72.8865
Fatiguing Exercise 1	FEIT1	122.4	86.8525	101.7445	115.9983	89.0863
	FEIM1	132.3	107.4890	104.2241	98.0002	99.5307
	FEIT2	142.4	84.0438	91.2009	107.8308	86.3593
	FEIM2	152.6	100.7474	99.6364	85.7994	104.2824
	FEIT3	162.7	81.4125	93.4112	100.5684	92.7797
	FEIM3	172.9	100.9215	98.6668	78.0806	87.5895
	FEIT4	182.4	78.9141	93.5957	83.3439	92.0770
	FEIM4	192.4	89.0711	93.8076	70.1254	85.5627
	FEIT5	202.6	77.1779	89.5513	77.0529	91.6760
	FEIM5	213.1	80.1183	97.5335	68.4526	84.0347
	FEIT6	224.2	74.1127	91.3636	74.9918	93.4513
	FEIM6	234.3	85.1859	94.5054	70.7213	84.5064
Piano Exercise 2	FFP21	248.1	80.7527	105.3326	92.4177	72.1428
	FFP22	273.1	98.6575	106.3488	96.5599	73.0667
	FFP23	283.0	95.4412	112.7814	93.4834	78.5205
	FFP24	307.9	86.9659	113.7246	93.0082	76.1761
	FFP25	318.1	95.9438	110.1262	94.8092	75.6630
	FFP26	343.0	98.7803	116.5083	93.9583	73.5357
Fatiguing Exercise 2	FEIT21	356.4	86.6397	97.2769	107.2758	97.0641
	FEIM21	366.4	103.8784	111.2514	87.3144	99.4344
	FEIT22	376.5	82.5435	101.3957	91.9175	98.0627
	FEIM22	386.6	89.4238	109.2155	76.2293	99.1135
	FEIT23	396.5	77.5693	95.5056	81.4864	90.2484
	FEIM23	407.4	90.6615	105.1245	75.3951	86.9119
Piano Exercise 3	FFP31	419.9	97.6948	110.3319	94.3619	74.9201
	FFP32	446.2	92.7210	109.1188	97.5203	75.5233
	FFP33	457.1	97.8336	117.1365	101.5831	64.7827
	FFP34	482.9	94.0842	116.1644	96.1672	78.9474
	FFP35	493.3	92.8343	117.4142	98.5280	74.3647
	FFP36	518.7	101.0205	114.8118	103.5030	82.9541

P1073F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	8.7	112.3783	123.7209	86.9806	124.0907
	FFP2	37.8	112.9673	126.3818	90.8583	121.0409
	FFP3	50.0	110.1484	124.8597	95.8110	125.6078
	FFP4	80.0	110.9647	119.2448	87.3792	122.3811
	FFP5	92.2	114.8440	128.8990	96.5972	132.8443
	FFP6	121.3	108.8137	123.0095	89.0631	126.9596
Fatiguing Exercise 1	FEIT1	138.9	75.2026	86.2541	69.4137	81.3072
	FEIM1	148.9	76.2153	110.7861	67.7056	98.5533
	FEIT2	158.9	75.4046	94.3717	68.8073	79.1156
	FEIM2	169.0	86.6751	106.4625	76.0446	95.0953
	FEIT3	179.1	75.3079	93.9375	67.2035	75.4131
	FEIM3	189.3	81.8988	115.1943	70.4567	91.6916
	FEIT4	199.2	69.4137	93.3060	63.9406	75.3079
	FEIM4	209.0	82.2875	115.1413	68.0033	89.1236
	FEIT5	218.7	70.7390	98.0922	68.5553	77.2900
	FEIM5	229.0	76.8278	111.4118	67.5626	85.9095
Piano Exercise 2	FFP21	242.8	113.7514	123.7502	92.2726	114.8624
	FFP22	272.0	112.2985	122.7972	95.3006	121.6723
	FFP23	284.1	117.0479	122.5472	93.1759	126.1717
	FFP24	313.2	110.7987	126.9216	95.3006	124.4219
	FFP25	325.3	110.5419	115.7265	96.7165	126.2190
	FFP26	354.4	114.6732	122.7972	93.3008	127.5466
Fatiguing Exercise 2	FEIT21	368.4	77.7497	88.5530	71.3136	79.4736
	FEIM21	378.4	84.7515	111.4797	74.8486	88.5011
	FEIT22	389.0	74.9401	92.2300	68.4824	73.1695
	FEIM22	398.2	90.0526	108.6399	75.5672	90.8217
	FEIT23	408.2	70.9853	89.6905	67.6235	72.9678
	FEIM23	419.3	82.1721	107.0631	68.1310	81.3211
	FEIT24	429.1	71.9196	84.4183	65.8786	74.9401
	FEIM24	439.7	82.5865	109.5651	68.4369	85.2278
	FEIT25	449.1	73.0035	90.5653	69.4142	76.7209
	FEIM25	458.8	75.8891	109.3765	73.7195	79.6623
	FEIT26	468.7	70.6033	93.7118	65.1594	73.1585
	FEIM26	479.1	80.6934	105.8312	71.9092	81.0672
	FEIT27	488.9	71.4123	95.0460	66.5265	74.3665
	FEIM27	498.9	74.1756	103.2112	63.5035	75.3293
Piano Exercise 3	FFP31	514.1	108.9372	118.4422	84.7426	120.7876
	FFP32	543.3	107.4559	112.1466	91.1616	128.5644
	FFP33	555.4	107.5491	119.0476	97.8003	124.7969
	FFP34	584.5	106.4683	118.9359	91.4085	114.7389
	FFP35	596.6	107.2090	119.0594	95.2352	123.5033
	FFP36	625.7	110.5487	115.9230	92.1760	121.6723

C9052F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	23.0	81.0966	105.7753	97.6339	77.0258
	FFP2	30.8	79.9514	105.8123	102.6117	81.2316
	FFP3	38.6	76.4261	98.7469	104.3597	74.7291
	FFP4	46.2	73.9119	103.1891	98.8760	82.4075
	FFP5	53.8	86.0520	105.3362	101.6378	72.1833
	FFP6	61.4	77.4198	106.1776	102.3166	78.0855
	FFP7	68.9	76.3334	101.2318	98.8730	76.0713
	FFP8	76.5	72.1465	110.6335	97.2755	76.3788
	FFP9	84.1	79.0579	99.6588	99.5276	79.5827
	FFP10	91.7	82.5319	100.9748	94.9150	75.9452
	FFP11	99.3	78.1394	102.5456	100.1837	79.9764
	FFP12	107.0	76.0291	108.3626	101.3505	78.1067
	FFP13	114.7	81.6340	103.3417	100.8420	79.5290
	FFP14	122.3	82.9113	100.9609	99.5325	76.0291
	FFP15	130.0	77.1609	102.2892	96.1058	78.6081
Fatiguing Exercise 1	FEIT1	146.8	93.8809	80.5487	88.5822	90.2914
	FEIM1	158.9	91.0205	96.3141	69.8461	87.9816
	FEIT2	170.0	74.9425	77.4423	86.3414	88.1412
	FEIM2	180.5	84.0800	90.3129	70.5752	89.0144
	FEIT3	189.4	76.1150	78.6990	77.4632	84.9905
	FEIM3	199.6	78.6475	82.0879	69.7237	98.0002
	FEIT4	209.3	75.3145	73.1642	78.2174	80.7978
	FEIM4	219.7	80.5587	76.8477	65.3025	74.1676
	FEIT5	229.5	72.6266	75.9596	78.6475	82.0879
	FEIM5	239.3	73.8093	82.8406	72.4116	88.7539
	FEIT6	249.4	71.9196	72.0237	77.3357	79.7313
	FEIM6	258.7	83.2173	86.2549	79.1672	91.9504
Piano Exercise 2	FFP21	270.5	75.1925	99.3785	109.3771	64.1130
	FFP22	277.9	76.1121	95.2932	108.2166	84.2742
	FFP23	285.1	73.0667	105.6496	107.0480	80.8978
	FFP24	292.3	77.5587	104.6382	106.0269	91.8622
	FFP25	299.5	75.6145	104.4994	107.1379	81.8636
	FFP26	306.7	75.1979	102.2775	103.2495	84.6410
	FFP27	314.0	76.0855	100.8766	107.8619	84.8514
	FFP28	321.3	83.0499	103.3193	102.9112	87.5391
	FFP29	328.6	75.7827	111.7777	108.0541	91.6425
	FFP30	335.9	74.4419	99.6439	106.6292	75.6746
	FFP31	343.1	81.5859	103.2495	108.9432	83.9467
	FFP32	350.3	84.2540	108.0268	42.4416	86.2117
	FFP33	357.4	81.3173	108.5862	103.6918	89.9874
	FFP34	364.6	74.2853	114.4205	99.6339	82.3124
	FFP35	371.7	79.7775	103.0137	80.0591	76.1160
Fatiguing Exercise 2	FEIT21	388.7	82.3849	78.1300	77.0663	54.0900
	FEIM21	399.0	96.8084	95.8994	88.3244	116.0994
	FEIT22	409.1	81.5019	75.6692	87.2305	87.1263
	FEIM22	419.2	88.6887	91.2926	70.4614	85.6682
	FEIT23	429.3	82.1269	77.2315	79.0022	74.5235
	FEIM23	439.3	83.6892	82.9601	69.5240	78.3773
	FEIT24	449.4	75.9394	77.7287	75.9394	80.7810
	FEIM24	459.5	88.2539	93.4112	72.7818	92.7797
	FEIT25	469.6	73.6238	75.6236	74.7816	75.3079
	FEIM25	479.6	78.5124	84.3281	76.3698	93.6129
	FEIT26	489.6	75.6236	78.1497	74.5711	74.8869
	FEIM26	500.6	76.5927	85.5660	70.1833	78.3874
	FEIT27	509.8	75.3145	78.2174	74.8844	77.4648
	FEIM27	519.8	73.8814	86.9104	63.6804	78.4264
	FEIT28	529.8	68.9820	74.8325	71.1095	73.8751
	FEIM28	539.9	72.4116	77.1422	79.4001	80.5827
Piano Exercise 3	FFP41	551.5	74.2037	96.0577	108.4845	79.7743
	FFP42	558.6	37.1277	102.0137	104.8105	62.9982
	FFP43	565.6	63.6864	91.7983	104.6950	73.2503
	FFP44	572.5	38.9074	98.1742	105.7093	73.3952
	FFP45	579.3	45.2917	99.1643	108.8643	64.9903
	FFP46	586.0	63.3488	98.4181	106.1782	71.8549
	FFP47	592.7	66.1842	97.5228	102.4474	74.8396
	FFP48	599.4	63.7025	98.2427	105.0598	83.3965
	FFP49	606.0	68.3987	102.4845	103.2419	76.4278
	FFP50	612.6	77.7912	100.8181	102.1815	76.4278
	FFP51	619.2	73.0950	98.3942	99.4546	78.7002
	FFP52	625.8	73.3473	96.0304	101.7012	77.3765
	FFP53	632.5	79.3165	90.3596	97.8212	78.8688
	FFP54	639.2	75.5857	97.8212	96.3289	78.8688
	FFP55	645.8	78.0797	104.3352	100.0611	72.7370

C9231F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	11.2	109.4001	130.1270	66.0488	73.4929
	FFP2	18.5	102.6663	125.8005	63.4558	68.5531
	FFP3	26.2	95.7723	124.1733	62.9620	68.9275
	FFP4	33.9	93.2138	120.4361	66.6366	71.9262
	FFP5	41.8	94.0730	119.7236	63.1926	67.9243
	FFP6	49.9	93.0900	114.5770	61.3478	64.0337
	FFP7	59.0	95.0206	117.8095	63.7988	68.8184
	FFP8	67.9	98.5392	120.8286	64.7903	68.4423
	FFP9	75.9	98.2809	125.5846	61.4967	66.4265
	FFP10	83.7	96.7142	120.8446	59.1067	68.9899
	FFP11	91.5	97.7235	124.2401	61.2469	66.4209
	FFP12	99.1	94.0165	126.8206	62.3934	68.0357
	FFP13	106.7	94.5874	117.9176	63.5249	71.1239
	FFP14	114.4	92.6634	121.7042	65.1509	72.0290
	FFP15	122.2	92.6163	123.3816	61.5947	64.2866
Fatiguing Exercise 1	FEIT1	136.6	71.4875	74.4769	86.3313	89.4238
	FEIM1	146.6	81.1895	93.3757	87.9596	87.2305
	FEIT2	156.7	71.7477	71.6413	71.0031	88.0226
	FEIM2	166.8	66.5395	80.6618	61.3854	76.6416
	FEIT3	177.0	68.0455	79.9390	66.7824	94.0427
	FEIM3	187.1	79.2186	90.6608	68.8073	81.1772
	FEIT4	197.0	74.6197	79.5128	74.9388	86.1079
	FEIM4	207.1	75.0934	80.4464	65.9024	78.7294
	FEIT5	217.3	69.6162	78.1099	66.0682	85.7435
	FEIM5	227.1	74.5799	84.3727	73.6522	83.4450
	FEIT6	237.2	70.9925	76.0446	72.3608	76.4656
	FEIM6	247.4	74.2006	81.7246	72.6166	84.9916
Piano Exercise 2	FFP21	264.4	101.4520	108.2028	64.5141	78.0155
	FFP22	272.1	103.1617	108.4313	63.4374	75.4628
	FFP23	279.5	106.6746	109.5881	64.2961	81.5124
	FFP24	286.9	102.9513	108.6057	59.6469	77.7134
	FFP25	294.3	100.1879	104.6168	65.6959	83.9485
	FFP26	301.6	100.1931	109.9848	64.3360	73.3002
	FFP27	308.9	100.4657	111.5601	62.9366	79.3727
	FFP28	316.3	100.5945	110.4580	66.2748	78.9758
	FFP29	323.7	100.0530	109.4557	64.4286	70.6529
	FFP30	331.2	96.5642	110.5221	60.0591	68.2459
	FFP31	338.7	93.7036	105.1885	63.8427	72.4902
	FFP32	346.1	101.1274	105.9589	60.4617	72.9432
	FFP33	353.5	96.1616	109.4484	60.5959	73.3459
	FFP34	361.2	93.2160	111.4416	65.6246	73.2186
	FFP35	369.1	97.7582	113.4250	64.3867	73.8123
Fatiguing Exercise 2	FEIT21	383.4	80.1495	79.5179	80.9915	92.8850
	FEIM21	393.4	80.7728	85.7723	79.3147	91.1884
	FEIT22	403.5	76.3983	78.8980	75.2526	92.4383
	FEIM22	413.4	92.7508	99.4167	86.6056	85.0432
	FEIT23	423.5	73.4133	83.4123	71.6240	96.6740
	FEIM23	433.4	82.2545	89.2011	78.2549	84.9911
	FEIT24	443.6	70.4567	82.5173	70.4567	97.4642
	FEIM24	453.7	74.4658	79.2022	70.6768	80.8862
	FEIT25	463.6	68.9104	80.7649	69.0135	94.8871
	FEIM25	473.6	77.8565	91.3967	71.6071	91.8134
	FEIT26	483.7	70.4567	81.4864	69.9412	95.5056
	FEIM26	494.0	77.9826	82.4919	66.7091	91.5106
	FEIT27	504.0	74.3006	81.5339	72.8114	94.1921
	FEIM27	513.9	80.2521	85.1474	75.3567	80.5645
	FEIT28	524.0	69.2032	80.3600	66.0457	93.6217
	FEIM28	534.1	73.0734	78.8304	68.4274	82.3654
Piano Exercise 3	FFP41	548.6	97.7571	93.8387	66.2748	82.6240
	FFP42	555.9	97.8336	98.3891	64.7827	77.2809
	FFP43	563.2	97.7263	99.0960	62.6626	83.8926
	FFP44	570.6	94.2259	96.8746	67.0772	82.7043
	FFP45	578.1	92.7210	95.7872	70.3240	83.1223
	FFP46	585.6	93.1209	95.7872	66.1912	79.3894
	FFP47	593.0	97.4697	101.1427	63.1887	81.2815
	FFP48	600.4	94.5511	105.0195	64.7564	72.1380
	FFP49	607.8	94.1249	102.2618	64.1980	74.1277
	FFP50	615.0	93.9870	103.6409	66.2667	70.8178
	FFP51	622.4	93.6962	102.7016	64.5610	75.9502
	FFP52	629.9	94.4169	101.7984	69.3196	75.3590
	FFP53	637.4	93.1209	103.5195	64.7247	79.7894
	FFP54	644.9	92.8543	100.8532	64.7247	71.2572
	FFP55	652.5	96.6972	101.8578	64.1853	72.8293

C9291M	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	13.6	111.0096	146.0845	115.3940	97.2476
	FFP2	21.7	109.6452	138.3032	121.7649	100.1767
	FFP3	29.7	104.4331	137.3158	115.7593	99.4398
	FFP4	38.0	108.3908	135.3524	113.4687	107.3026
	FFP5	46.1	112.6104	136.4880	109.9988	105.5217
	FFP6	54.2	104.4223	136.8606	111.2259	97.0113
	FFP7	62.4	102.5338	135.4490	120.0472	103.1549
	FFP8	70.5	108.1462	133.0512	114.6485	108.3916
	FFP9	78.5	104.2925	134.1087	110.4614	107.6340
	FFP10	86.2	109.8164	130.3867	113.8524	104.4786
	FFP11	94.1	108.2085	132.8096	106.7470	105.2856
	FFP12	102.3	111.0767	136.7241	115.5371	100.2974
	FFP13	110.3	109.9863	138.3058	116.8178	103.6517
	FFP14	118.3	108.0996	134.6372	109.3573	97.5349
	FFP15	126.5	106.1920	131.6106	116.4318	106.0716
Fatiguing Exercise 1	FEIT1	138.6	115.4836	96.9706	90.8326	130.7296
	FEIM1	148.9	97.1549	126.3272	67.7765	100.5566
	FEIT2	158.9	97.4351	97.7611	70.9162	124.4973
	FEIM2	168.9	107.9786	129.9351	70.6628	77.4662
	FEIT3	178.9	107.2166	100.4782	74.3941	120.6934
	FEIM3	188.9	96.9094	125.2904	66.9124	121.9574
	FEIT4	199.1	101.7633	94.0221	93.8071	123.9114
	FEIM4	209.0	96.6740	122.0398	73.8343	136.1436
	FEIT5	219.2	97.7024	94.7240	71.9604	122.4870
	FEIM5	229.2	102.7497	120.3520	73.2736	29.8406
	FEIT6	239.4	99.6289	97.3611	79.7340	125.6056
	FEIM6	249.3	95.0973	113.0524	68.9711	85.3134
Piano Exercise 2	FFP21	266.0	95.6929	124.6635	116.9722	103.5124
	FFP22	273.6	97.1785	121.0108	112.3819	101.6984
	FFP23	280.9	96.2454	127.2616	109.7130	96.7896
	FFP24	288.2	98.5481	130.7355	103.8899	101.4245
	FFP25	295.5	100.0544	130.5265	114.4742	102.9112
	FFP26	303.0	98.7286	134.0882	116.8719	99.7881
	FFP27	310.6	100.4415	127.9704	112.9074	98.1041
	FFP28	318.2	101.5300	127.9694	113.0721	100.0537
	FFP29	325.8	98.6324	133.4666	111.1469	94.5039
	FFP30	333.5	96.7847	135.6032	116.1286	101.4900
	FFP31	341.0	101.3958	139.9141	113.4747	90.3906
	FFP32	348.4	102.9513	132.0508	108.6057	97.1590
	FFP33	355.7	105.8247	131.0562	114.2800	95.2221
	FFP34	363.2	100.1892	134.1035	106.8099	89.1096
	FFP35	370.7	105.6725	136.9102	112.9918	92.6023
Fatiguing Exercise 2	FEIT21	383.8	114.4873	107.9325	95.8227	128.5968
	FEIM21	393.8	104.5395	136.6363	69.4431	109.4391
	FEIT22	404.1	108.4292	102.8384	74.2393	124.4490
	FEIM22	414.1	107.4097	130.5652	75.0974	87.3066
	FEIT23	424.1	104.9356	102.3827	89.2990	117.4875
	FEIM23	434.1	115.1443	119.7271	78.0648	115.1443
	FEIT24	444.3	100.5684	94.7795	94.8847	126.9866
	FEIM24	454.2	104.3121	113.2695	78.6897	101.0832
	FEIT25	464.4	100.1489	96.4259	76.5344	129.7202
	FEIM25	474.3	102.4629	109.8305	67.8350	147.0898
	FEIT26	484.4	103.8719	100.2553	85.1505	125.4654
	FEIM26	494.3	107.9575	122.5393	48.0679	109.9365
	FEIT27	504.5	102.9892	96.0425	63.5196	124.2501
	FEIM27	514.4	97.5960	98.9788	64.8335	93.7666
	FEIT28	524.5	102.3576	95.6215	76.3604	126.3551
	FEIM28	534.5	96.8779	106.6728	74.9413	99.8368
	FEIT29	544.7	102.2524	92.0429	70.1505	122.9871
	FEIM29	554.7	99.6289	105.5046	71.5906	89.0114
	FEIT30	564.9	95.2995	94.6810	30.7700	129.8320
	FEIM30	575.0	93.0007	115.4474	27.5992	87.2870
	FEIT31	584.9	101.6921	94.2204	67.7398	119.3825
	FEIM31	594.5	101.2257	104.1286	34.9962	32.9534
Piano Exercise 3	FFP41	608.5	97.7582	128.4550	107.4385	90.8801
	FFP42	616.1	102.5031	130.1184	109.8490	95.0211
	FFP43	623.5	102.0950	128.0778	118.2832	96.1094
	FFP44	630.8	91.9184	131.4991	116.4667	99.2277
	FFP45	637.9	102.1997	132.1954	113.4838	98.4859
	FFP46	645.0	94.8818	130.8209	102.4332	95.7209
	FFP47	652.0	101.2172	129.1842	117.0120	90.2043
	FFP48	659.1	100.7396	132.2422	117.7236	100.3287
	FFP49	666.3	100.9013	130.0521	116.8145	87.5229
	FFP50	673.3	101.9278	131.4199	121.4933	95.7416
	FFP51	680.4	95.5499	130.0521	118.2228	93.5784
	FFP52	687.4	100.7658	131.6834	113.6718	87.1508
	FFP53	694.6	103.5273	131.7178	117.9697	99.2223
	FFP54	701.6	102.2316	135.1253	117.4467	95.7108
	FFP55	708.5	101.5180	132.1705	115.0927	106.0429

C10101F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	7.7	121.5694	130.7177	104.4324	72.2201
	FFP2	16.0	118.6296	123.3041	104.8341	76.2171
	FFP3	24.8	118.6585	123.9927	108.8980	80.2974
	FFP4	33.6	122.5429	125.4971	104.7040	73.5712
	FFP5	42.4	110.0557	124.5023	102.3206	74.7924
	FFP6	51.2	112.8849	119.8159	101.5226	76.7526
	FFP7	59.9	116.5570	127.9875	108.0129	70.9502
	FFP8	68.6	113.7384	129.9620	99.0105	73.3517
	FFP9	77.2	115.9887	120.2087	103.3290	75.7824
	FFP10	85.7	114.8814	137.6592	98.0610	80.7733
	FFP11	94.2	113.8264	121.3638	102.7559	70.3686
	FFP12	102.7	114.0951	124.2474	108.4288	69.1182
	FFP13	111.2	113.2220	132.3962	97.4591	79.2260
	FFP14	119.7	111.4748	126.4730	103.0234	76.9551
	FFP15	128.2	112.6459	112.6459	103.8608	77.2743
Fatiguing Exercise 1	FEIT1	142.7	91.4114	110.3568	73.6238	74.0448
	FEIM1	153.0	97.6213	117.4087	68.8875	43.7322
	FEIT2	162.6	94.3178	110.2914	67.9795	64.6872
	FEIM2	172.5	96.5798	115.1762	66.8629	45.3696
	FEIT3	183.0	93.7682	108.0688	66.3295	63.8879
	FEIM3	192.9	102.4156	97.3666	62.8156	44.4015
	FEIT4	202.6	87.4893	106.9991	64.5653	62.1266
	FEIM4	212.6	93.6828	95.2715	59.5739	39.4823
	FEIT5	224.0	88.9304	104.3834	64.7914	51.1564
	FEIM5	234.3	90.9409	100.4400	64.1436	39.8460
	FEIT6	244.8	90.5520	109.2235	63.7180	54.6373
	FEIM6	254.9	91.5009	95.8754	62.0248	40.3604
Piano Exercise 2	FFP21	266.9	104.9244	100.9249	109.9238	77.6778
	FFP22	275.0	106.9621	105.9746	109.5544	79.6815
	FFP23	283.1	114.7712	97.3500	101.3986	75.2668
	FFP24	291.1	112.8789	121.3055	109.8604	81.4363
	FFP25	299.2	114.9858	108.1965	108.6903	72.8922
	FFP26	307.2	113.1734	103.1746	109.2988	83.9270
	FFP27	315.3	114.8624	119.0594	104.4933	76.7189
	FFP28	323.3	118.4027	131.5656	104.9867	76.2562
	FFP29	331.2	115.2981	113.4233	104.9244	78.0527
	FFP30	339.2	119.0476	115.4231	100.9249	77.8028
	FFP31	347.2	117.7839	115.0170	108.8542	75.3993
	FFP32	355.1	112.3758	115.8974	103.0688	78.4178
	FFP33	363.1	120.6809	115.4917	104.6070	73.7248
	FFP34	371.0	114.4232	120.0475	100.7999	69.6788
	FFP35	379.1	115.9733	121.1579	106.0980	75.2376
Fatiguing Exercise 2	FEIT21	391.5	89.7962	109.5372	78.2592	70.8243
	FEIM21	397.8	92.1559	99.8462	72.9300	54.9859
	FEIT22	403.2	93.5184	105.0681	72.1427	71.7980
	FEIM22	412.0	103.7995	112.4234	78.6777	48.0565
	FEIT23	421.1	90.5694	111.5146	68.4665	72.1503
	FEIM23	431.2	97.3403	110.1390	69.3431	49.2451
	FEIT24	441.3	88.7404	111.8900	71.5683	67.2210
	FEIM24	451.2	93.5406	102.3398	72.5427	47.9452
	FEIT25	461.5	87.8626	104.7916	67.1716	68.7556
	FEIM25	471.6	93.8730	97.3833	73.0241	52.9199
	FEIT26	482.2	94.5148	107.4660	65.1843	63.7558
	FEIM26	491.2	91.1058	110.3567	56.7826	46.4856
Piano Exercise 3	FFP41	505.2	102.7651	105.1105	108.8137	84.8661
	FFP42	513.2	106.6742	108.2990	107.6740	90.5512
	FFP43	521.2	114.7323	115.1120	112.9604	79.2938
	FFP44	529.1	112.9604	121.6935	105.3664	76.7624
	FFP45	537.0	109.0368	113.5932	109.7962	81.9517
	FFP46	544.8	113.1265	112.6138	109.9218	85.6941
	FFP47	552.6	109.7278	112.4371	107.4055	76.8288
	FFP48	560.4	111.3871	114.8261	105.9101	87.6958
	FFP49	568.3	113.2135	117.8965	106.2524	72.5857
	FFP50	576.1	110.1782	112.7420	104.7943	74.5417
	FFP51	583.9	109.1527	107.7426	107.8708	81.5921
	FFP52	591.7	108.9670	111.1323	101.4520	73.0480
	FFP53	599.5	107.1475	113.2112	103.9221	87.4081
	FFP54	607.3	112.3880	120.5688	105.5058	74.2111
	FFP55	615.0	112.6477	119.9195	104.8565	77.3276

C10102F	Short Form	Time	Ch1 EDC MDF	Ch2 ECU MDF	Ch3 FDS MDF	Ch4 FCU MDF
Piano Exercise 1	FFP1	19.0	96.7948	145.3374	93.7754	93.7754
	FFP2	27.7	97.7704	135.9914	95.4954	92.9928
	FFP3	36.5	97.5596	138.5719	92.2495	89.0860
	FFP4	45.4	95.7374	138.9298	92.7899	88.1419
	FFP5	54.3	93.2599	135.3020	95.3732	81.9152
	FFP6	63.3	94.2481	133.5971	90.7926	85.5535
	FFP7	72.3	94.2457	137.8952	39.6565	94.4645
	FFP8	81.3	96.6291	132.8436	58.1369	86.0380
	FFP9	90.2	96.2504	130.5100	60.5401	94.2417
	FFP10	99.1	92.0187	131.9251	66.4920	89.7893
	FFP11	108.6	98.3402	133.7366	68.8431	53.5446
	FFP12	118.1	92.0683	141.2763	88.4732	84.0917
	FFP13	127.0	94.6523	136.3330	90.6078	82.1818
	FFP14	135.9	91.8231	139.7067	93.1563	93.2674
	FFP15	144.8	90.7283	134.8142	83.4564	30.1670
Fatiguing Exercise 1	FEIT1	157.4	92.6193	124.6779	81.7957	78.9094
	FEIM1	167.4	101.1303	137.9741	67.6557	85.1538
	FEIT2	177.4	86.9908	122.8818	85.2016	78.6759
	FEIM2	186.4	91.8119	118.7002	60.7350	76.6788
	FEIT3	197.6	86.0436	121.1978	73.4133	82.1492
	FEIM3	207.6	91.6219	121.0925	63.6249	77.3077
	FEIT4	217.6	79.9390	122.6713	70.1505	78.9917
	FEIM4	227.6	83.8180	121.5692	61.9835	80.6550
	FEIT5	237.6	83.7677	119.9340	69.9394	79.5128
	FEIM5	247.8	79.6420	120.2380	57.6442	75.5424
Piano Exercise 2	FFP21	260.2	79.8152	119.6936	97.0062	45.0824
	FFP22	268.7	83.3236	123.7867	101.0993	90.1064
	FFP23	277.3	84.9320	127.4852	103.4182	96.0935
	FFP24	286.0	84.6454	119.9287	92.0009	92.9204
	FFP25	294.6	84.4018	117.2215	94.5183	88.8719
	FFP26	303.2	86.3744	119.5910	98.1245	88.5211
	FFP27	311.9	80.2830	120.3953	95.2520	93.0301
	FFP28	320.6	84.8474	120.6148	93.8750	87.4757
	FFP29	329.4	88.6493	121.4948	96.6931	91.3306
	FFP30	338.2	85.9438	123.1650	91.3767	89.8740
	FFP31	346.8	85.3429	115.9275	98.5178	93.2243
	FFP32	355.4	84.5567	120.9687	98.6591	83.8631
	FFP33	364.1	85.6798	119.0093	102.6893	86.9440
	FFP34	372.8	87.1739	118.8944	95.7936	86.3694
	FFP35	381.4	89.0013	117.9514	92.7218	88.5362
Fatiguing Exercise 2	FEIT21	393.8	87.6382	128.2381	79.3062	80.8211
	FEIM21	402.4	99.3401	134.4366	69.5430	76.6423
	FEIT22	412.6	87.2013	129.7232	77.6234	84.6753
	FEIM22	422.6	83.5774	122.4624	67.3164	80.4464
	FEIT23	432.6	84.2383	126.2767	68.4335	77.6798
	FEIM23	442.5	82.6684	130.9464	63.0744	78.2244
	FEIT24	452.7	83.0327	124.0594	67.2611	76.9508
	FEIM24	462.7	90.6967	123.8452	59.2870	76.0243
	FEIT25	472.6	82.1269	124.1017	66.8160	78.1689
	FEIM25	482.8	74.4312	120.7530	56.5759	63.5139
	FEIT26	492.9	79.3074	118.8822	64.7827	74.4658
	FEIM26	503.0	75.8596	123.2017	64.6363	74.2271
Piano Exercise 3	FFP41	515.0	81.1557	111.9495	99.8037	95.6324
	FFP42	523.2	82.2461	111.9985	104.6824	97.3662
	FFP43	531.4	82.6119	116.1444	103.3411	96.0249
	FFP44	539.5	86.9646	112.5170	103.1354	94.6179
	FFP45	547.7	85.4716	110.1674	98.6026	90.2903
	FFP46	555.9	84.3455	114.0351	95.8778	92.3200
	FFP47	564.3	84.0253	112.6769	96.1876	99.2282
	FFP48	572.7	82.9242	117.8901	89.8695	101.6046
	FFP49	581.0	85.5383	117.7295	93.2203	98.7075
	FFP50	589.2	88.3224	116.5905	96.5930	94.0007
	FFP51	597.2	88.1021	120.9282	97.5349	91.8752
	FFP52	605.3	85.5921	118.1183	93.5429	80.2915
	FFP53	613.6	84.2414	119.0875	99.2097	90.7077
	FFP54	622.0	89.8107	120.6404	95.8814	94.8101
	FFP55	630.5	90.7540	118.7507	91.5775	92.0480

Appendix G

Plots of Each Participant's MDF Values in Sequence by Activity Unit

Participant P9052F

Participant P9191F

Participant P9192F

Participant P9193M

Participant P9231F

Participant P9291F

Participant P1031F

Participant P1032F

Participant P1071F

Participant P1072F

Participant P1073F

Participant C9052F

Participant C9231F

Participant C9291M

Participant C10101F

Participant C10102F

Appendix H

MDF Plots of Fatiguing Exercise Static and Dynamic Segments for All Participants

Fatiguing Exercise 1 Static (Isotonic/Isometric) - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.7830	0.7370	0.8638	0.2798	0.1387	0.4915	0.6094	0.6618	0.5231	0.8543	0.0131	0.4021	0.0247	0.0804	0.4869	0.9404
Slope ±	-1	-1	-1	1	1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Fatiguing Exercise 2 Static (Isotonic/Isometric) - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.9306	0.8494	0.7738	0.4316	0.2017	0.7199	0.7386	0.3099	0.5760	0.6718	0.6722	0.8990	0.3691	0.4775	0.2340	0.6090
Slope ±	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Fatiguing Exercise 1 Static (Isotonic/Isometric) - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.7750	0.7803	X	0.2650	0.8933	0.4624	0.3026	0.1570	0.4253	0.7047	0.1904	0.3794	0.3072	0.8087	0.6636	0.4101
Slope ±	-1	-1	X	1	-1	-1	-1	1	-1	-1	1	-1	-1	-1	-1	-1
Fatiguing Exercise 2 Static (Isotonic/Isometric) - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.6291	0.9171	X	0.1240	0.0046	0.6601	0.0375	0.2906	0.7796	0.9672	0.6211	0.5433	0.2972	0.5634	0.0011	0.4521
Slope ±	-1	-1	X	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1

Fatiguing Exercise 1 Static (Isotonic/Isometric) - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.0069	0.7531	0.2206	0.7754	0.7000	0.5597	0.4028	0.4223	0.0336	0.8214	0.1331	0.3060	0.0631	0.1493	0.5093	0.6325
Slope ±	1	-1	1	-1	-1	-1	-1	-1	1	-1	-1	1	-1	1	-1	-1
Fatiguing Exercise 2 Static (Isotonic/Isometric) - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.7224	0.6481	0.3440	0.6641	0.2121	0.8660	0.8242	0.8630	0.4565	0.7949	0.4035	0.1252	0.5397	0.0563	0.4899	0.4419
Slope ±	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Fatiguing Exercise 1 Static (Isotonic/Isometric) - FCU															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.6537	0.0129	0.2207	0.6623	0.2500	0.8565	0.9427	0.2061	0.4973	0.7084	0.9978	0.0013	0.0083	0.0022	0.6236
Slope ±	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1

Fatiguing Exercise 2 Static (Isotonic/Isometric) - FCU															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.0135	0.7182	0.0040	0.1196	0.2263	0.7478	0.5454	0.3917	0.5831	0.7769	0.7625	0.4081	0.1055	0.1071	0.1949
Slope ±	-1	-1	1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Fatiguing Exercise 1 Dynamic (Isotonic) - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.7691	0.8043	0.7431	0.7332	0.1681	0.6172	0.1870	0.5444	0.4399	0.9961	0.6619	0.6117	0.0032	0.4115	0.2814	0.7088
Slope ±	-1	-1	-1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Fatiguing Exercise 2 Dynamic (Isotonic) - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.8171	0.8840	0.8045	0.2320	0.0502	0.7801	0.2197	0.7035	0.4486	0.9966	0.5890	0.8140	0.5201	0.5283	0.0096	0.9665
Slope ±	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1

Fatiguing Exercise 1 Dynamic (Isotonic) - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.3472	0.7252	X	0.3616	0.1063	0.6855	0.8624	0.0007	0.3402	0.4861	0.6881	0.7450	0.2014	0.0989	0.3220	0.7272
Slope ±	-1	-1	X	1	-1	-1	-1	-1	-1	-1	1	-1	1	-1	-1	-1
Fatiguing Exercise 2 Dynamic (Isotonic) - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.8547	0.7967	X	0.1051	0.3664	0.6546	0.4946	0.0942	0.7417	0.0847	0.2560	0.0432	0.0502	0.6796	0.0376	0.8522
Slope ±	-1	-1	X	-1	-1	-1	-1	1	-1	-1	1	-1	1	-1	-1	-1

Fatiguing Exercise 1 Dynamic (Isotonic) - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.6133	0.2535	0.2229	0.0597	0.0380	0.9788	0.8011	0.7674	0.3759	0.9522	0.2306	0.7097	0.3082	0.0321	0.7854	0.7683
Slope ±	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1
Fatiguing Exercise 2 Dynamic (Isotonic) - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.5173	0.3388	0.7155	0.8405	0.0999	0.8342	0.6451	0.8237	0.7391	0.9884	0.4755	0.5193	0.6308	0.4898	0.7403	0.8497
Slope ±	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Fatiguing Exercise 1 Dynamic (Isotonic) - FCU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.2843	0.6631	0.4640	0.0612	0.1679	0.7113	0.4732	0.6399	0.0595	0.5472	0.5420	0.9063	0.5328	0.1966	0.8477	0.0287
Slope ±	-1	-1	1	1	1	-1	1	-1	-1	1	-1	-1	-1	-1	-1	1
Fatiguing Exercise 2 Dynamic (Isotonic) - FCU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.6283	0.0006	0.0002	0.1412	0.0237	0.4191	0.2815	0.9607	0.5796	0.6401	0.1398	0.4135	0.0163	0.0126	0.7253	0.6245
Slope ±	-1	-1	-1	1	1	-1	1	-1	-1	-1	-1	-1	1	-1	-1	-1

Appendix I

Power Plots of Fatiguing Exercise Static and Dynamic Segments for All Participants

Fatiguing Exercise 1 Static (Isotonic/Isometric) - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.4906	0.3969	0.8295	0.6658	0.4118	0.7265	0.8847	0.1671	0.5544	0.5422	0.7280	0.0079	0.0948	0.3383	0.5821	0.6159
Slope ±	-1	1	-1	1	-1	1	1	-1	-1	1	-1	1	-1	1	-1	-1
Fatiguing Exercise 2 Static (Isotonic/Isometric) - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.2932	0.8689	0.0692	0.0373	0.1988	0.4887	0.0646	0.5379	0.1988	0.8293	0.0015	0.9415	0.1595	0.4096	0.1267	0.5510
Slope ±	1	1	1	1	1	1	-1	1	-1	1	1	1	-1	-1	-1	1

Fatiguing Exercise 1 Static (Isotonic/Isometric) - ECU															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.8722	0.6947	X	0.1186	0.7317	0.8830	0.0411	0.0428	0.7858	0.1290	0.2960	0.5907	0.0223	0.0262	0.7212
Slope ±	-1	-1	X	1	-1	1	1	1	-1	-1	1	1	1	1	-1

Fatiguing Exercise 2 Static (Isotonic/Isometric) - ECU															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.7661	0.1873	X	0.0289	0.5886	0.4001	0.5559	0.0000	0.3768	0.1074	0.0331	0.9164	0.0248	0.5948	0.0323
Slope ±	-1	1	X	-1	1	1	-1	-1	-1	-1	1	1	-1	-1	1

Fatiguing Exercise 1 Static (Isotonic/Isometric) - FDS															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.7501	0.8754	0.8014	0.8593	0.9602	0.2549	0.2596	0.6942	0.9358	0.1820	0.7562	0.0743	0.6168	0.2168	0.5959
Slope ±	-1	-1	-1	-1	-1	-1	1	-1	-1	1	-1	-1	-1	-1	-1

Fatiguing Exercise 2 Static (Isotonic/Isometric) - FDS															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.0161	0.6316	0.0001	0.7688	0.9333	0.0263	0.1062	0.0857	0.9638	0.4692	0.2846	0.6933	0.0588	0.2562	0.0141
Slope ±	-1	1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	-1	1

Fatiguing Exercise 1 Static (Isotonic/Isometric) - FCU															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.8631	0.9641	0.8149	0.8937	0.9949	0.7424	0.9515	0.8806	0.9693	0.0000	0.8365	0.1994	0.4372	0.0830	0.9907
Slope ±	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	1	-1	1	-1

Fatiguing Exercise 2 Static (Isotonic/Isometric) - FCU															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.8975	0.9604	0.3546	0.9014	0.9983	0.6512	0.9090	0.8810	0.9893	0.7370	0.0684	0.3845	0.4249	0.0042	0.9774
Slope ±	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	1	-1

Fatiguing Exercise 1 Dynamic (Isotonic) - EDC															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.0283	0.7112	0.5863	0.7510	0.4734	0.3779	0.8090	0.0931	0.7859	0.7742	0.7700	0.4679	0.0012	0.0528	0.1750
Slope ±	-1	1	-1	1	-1	1	1	-1	-1	1	-1	1	-1	1	1

Fatiguing Exercise 2 Dynamic (Isotonic) - EDC															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.7777	0.9400	0.6594	0.1839	0.0556	0.7181	0.2485	0.1975	0.3278	0.9629	0.0204	0.7921	0.5546	0.1478	0.3666
Slope ±	1	1	1	1	1	1	1	-1	-1	1	-1	1	1	-1	1

Fatiguing Exercise 1 Dynamic (Isotonic) - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.4274	0.7837	X	0.9436	0.5229	0.8911	0.3210	0.3376	0.6862	0.5186	0.0215	0.8407	0.0257	0.2523	0.2892	0.3756
Slope ±	-1	-1	X	1	-1	1	1	-1	-1	-1	1	1	-1	1	-1	1
Fatiguing Exercise 2 Dynamic (Isotonic) - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R^2	0.6710	0.0121	X	0.0340	0.1704	0.4032	0.1648	0.9068	0.0258	0.7223	0.0093	0.8234	0.0475	0.4062	0.0095	0.5638
Slope ±	-1	-1	X	-1	-1	1	-1	-1	1	1	1	1	1	-1	1	1

Fatiguing Exercise 1 Dynamic (Isotonic) - FDS															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.2009	0.3496	0.0028	0.0214	0.9411	0.7048	0.7764	0.3346	0.7421	0.0847	0.4848	0.0484	0.6500	0.1527	0.4941
Slope ±	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1

Fatiguing Exercise 2 Dynamic (Isotonic) - FDS															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.6954	0.1847	0.0703	0.7519	0.7621	0.4644	0.3518	0.3922	0.8570	0.9827	0.6064	0.3640	0.0800	0.6845	0.5553
Slope ±	1	-1	1	-1	-1	-1	-1	-1	-1	-1	1	1	1	-1	-1

Fatiguing Exercise 1 Dynamic (Isotonic) - FCU															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.1254	0.2852	0.0548	0.0724	0.9348	0.9211	0.9059	0.3876	0.8991	0.7489	0.9270	0.8360	0.5342	0.0001	0.8656
Slope ±	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1

Fatiguing Exercise 2 Dynamic (Isotonic) - FCU															
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F
R ²	0.3249	0.2471	0.1023	0.9116	0.7527	0.5500	0.6730	0.6532	0.7708	0.0690	0.4008	0.0149	0.3830	0.1417	0.6090
Slope ±	-1	-1	1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	-1	-1

Appendix J

MDF Plots of Piano Exercise Segments for All Participants

Piano Exercise 1 - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.5691	0.5719	0.0706	0.6371	0.1205	0.0541	0.0001	0.0002	0.2314	0.0010	0.0981	0.0036	0.3041	0.0009	0.4536	0.3849
Slope ±	1	1	-1	1	1	-1	1	-1	1	1	-1	1	-1	-1	-1	-1
Piano Exercise 2 - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.1059	0.3410	0.1262	0.2936	0.1396	0.8942	0.8093	0.3875	0.3347	0.3067	0.0298	0.2291	0.5814	0.6032	0.4235	0.4052
Slope ±	1	1	1	1	1	1	1	1	1	1	-1	1	-1	1	1	1
Piano Exercise 3 - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.7095	0.5018	0.3949	0.3928	0.0129	0.5128	0.8016	0.7173	0.9113	0.0378	0.0521	0.3637	0.2251	0.0831	0.0587	0.5579
Slope ±	1	1	1	1	1	1	1	-1	1	1	1	1	-1	1	1	1

Piano Exercise 1 - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.2096	0.1537	X	0.4032	0.0369	0.2399	0.1963	0.0022	0.2584	0.0568	0.0071	0.0214	0.0273	0.3593	0.0186	0.0750
Slope ±	-1	-1	X	1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1
Piano Exercise 2 - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.3267	0.5291	X	0.8340	0.3045	0.8871	0.9619	0.0207	0.7188	0.7066	0.0583	0.3057	0.0855	0.5415	0.3498	0.1801
Slope ±	1	1	X	1	1	1	1	1	1	1	-1	1	1	1	1	-1
Piano Exercise 3 - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.2415	0.8275	X	0.8252	0.2911	0.2881	0.9310	0.0289	0.7735	0.4097	0.0057	0.0114	0.5088	0.4090	0.1449	0.6830
Slope ±	1	1	X	1	1	1	1	-1	1	1	1	1	1	1	1	1

Piano Exercise 1 - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.2971	0.5962	0.0797	0.0093	0.1394	0.1336	0.0537	0.1478	0.8922	0.4736	0.0297	0.1178	0.1461	0.0714	0.0968	0.1403
Slope ±	1	1	-1	-1	1	-1	-1	1	-1	-1	1	-1	-1	-1	-1	-1
Piano Exercise 2 - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.1181	0.0259	0.1855	0.3059	0.4957	0.1799	0.0156	0.1086	0.3189	0.0125	0.1388	0.3068	0.0131	0.0125	0.2559	0.0282
Slope ±	1	1	1	1	1	-1	-1	1	1	1	1	-1	-1	-1	-1	-1
Piano Exercise 3 - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.0537	0.2769	0.1674	0.2903	0.6239	0.4859	0.6714	0.2844	0.4822	0.4478	0.2352	0.7276	0.0082	0.2032	0.4474	0.4162
Slope ±	1	-1	1	-1	-1	1	1	1	1	1	1	-1	-1	1	-1	-1

Piano Exercise 1 - FCU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.0033	0.2119	0.1107	0.0033	0.2091	0.1612	0.2154	0.0300	0.1997	0.1889	0.2597	0.0031	0.0696	0.0554	0.0050	0.0532
Slope ±	1	-1	1	-1	-1	1	1	-1	-1	-1	1	1	-1	1	1	-1
Piano Exercise 2 - FCU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.4319	0.0909	0.6962	0.4760	0.1226	0.0140	0.0536	0.0289	0.1727	0.0548	0.7298	0.0366	0.3392	0.5760	0.2116	0.3111
Slope ±	1	1	1	-1	1	-1	1	1	-1	1	1	-1	-1	-1	-1	-1
Piano Exercise 3 - FCU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.0001	0.4426	0.5452	0.8555	0.0270	0.0298	0.0567	0.0111	0.0066	0.2579	0.0622	0.1735	0.4760	0.0362	0.1735	0.1371
Slope ±	-1	-1	1	-1	-1	1	-1	-1	1	1	-1	1	-1	1	-1	-1

Appendix K

Power Plots of Piano Exercise Segments for All Participants

Piano Exercise 1 - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.3791	0.1700	0.3646	0.9796	0.5052	0.0282	0.5189	0.8271	0.9190	0.5508	0.5532	0.1423	0.5781	0.0021	0.1677	0.6241
Slope ±	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	1	-1	-1	1	-1
Piano Exercise 2 - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.0232	0.5560	0.4817	0.8751	0.9150	0.2984	0.0792	0.9363	0.5293	0.1037	0.4477	0.6244	0.6716	0.0628	0.5033	0.6864
Slope ±	1	-1	-1	-1	-1	-1	1	-1	-1	-1	1	1	-1	1	1	-1
Piano Exercise 3 - EDC																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.0352	0.7941	0.4883	0.8566	0.9851	0.0699	0.0002	0.6444	0.6340	0.4757	0.7060	0.0470	0.7258	0.3956	0.5416	0.3905
Slope ±	1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	1	-1	1	-1	-1

Piano Exercise 1 - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.0009	0.4522	X	0.0687	0.2510	0.3538	0.0005	0.1577	0.7232	0.0668	0.1335	0.0111	0.2846	0.0309	0.0032	0.5210
Slope ±	-1	1	X	-1	1	1	-1	-1	-1	-1	-1	1	-1	1	1	-1
Piano Exercise 2 - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.2496	0.2423	X	0.1052	0.2395	0.2813	0.6442	0.7606	0.2345	0.0650	0.4814	0.5861	0.7640	0.4694	0.0791	0.7641
Slope ±	1	1	X	-1	1	1	-1	-1	1	1	1	1	-1	1	1	-1
Piano Exercise 3 - ECU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.2076	0.3628	X	0.4031	0.7233	0.1537	0.4020	0.4628	0.5341	0.2958	0.7819	0.3521	0.6826	0.3279	0.4839	0.0589
Slope ±	1	1	X	1	-1	1	-1	-1	-1	-1	-1	1	-1	1	-1	-1

Piano Exercise 1 - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.5240	0.5821	0.4933	0.6299	0.6172	0.7018	0.8384	0.2447	0.8004	0.5266	0.6547	0.1268	0.1444	0.1504	0.0441	0.0971
Slope ±	-1	1	-1	1	-1	1	-1	1	-1	1	1	1	-1	-1	-1	-1
Piano Exercise 2 - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.5742	0.3223	0.5767	0.0236	0.8808	0.7287	0.7956	0.0354	0.9788	0.1900	0.2847	0.8729	0.7869	0.5245	0.4886	0.0189
Slope ±	1	-1	-1	1	-1	1	-1	-1	-1	1	1	1	1	1	1	1
Piano Exercise 3 - FDS																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.2874	0.0179	0.4719	0.5053	0.9655	0.5517	0.7893	0.0166	0.7852	0.1801	0.0163	0.6410	0.3789	0.3906	0.1476	0.1314
Slope ±	1	-1	-1	1	-1	1	-1	-1	-1	1	-1	1	1	1	1	1

Piano Exercise 1 - FCU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.2082	0.1452	0.1237	0.7494	0.5021	0.5051	0.5175	0.0427	0.9757	0.0300	0.7718	0.1702	0.2412	0.0430	0.1608	0.4786
Slope ±	-1	-1	1	-1	-1	1	-1	-1	-1	-1	1	1	-1	1	-1	-1
Piano Exercise 2 - FCU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.2419	0.5614	0.7654	0.7558	0.5154	0.2508	0.0497	0.0823	0.9635	0.0636	0.5079	0.5515	0.2963	0.0009	0.0721	0.0016
Slope ±	1	-1	1	-1	-1	1	-1	-1	-1	1	1	1	1	1	1	1
Piano Exercise 3 - FCU																
	P9052F	P9191F	P9192F	P9193M	P9231F	P9291F	P1031F	P1032F	P1071F	P1072F	P1073F	C9052F	C9231F	C9291M	C10101F	C10102F
R ²	0.6684	0.8938	0.5824	0.0486	0.9290	0.1621	0.4183	0.0408	0.9255	0.2746	0.0065	0.4996	0.0020	0.0199	0.0428	0.4646
Slope ±	1	-1	1	1	-1	1	-1	1	-1	-1	1	1	1	-1	1	1

References

1. Zaza C, Charles C, Muszynski A. The meaning of playing-related musculoskeletal disorders to classical musicians. *Soc Sci Med*. 1998;47(12):2013–23.
2. Bruno S, Lorusso A, L' Abbate N. Playing-related disabling musculoskeletal disorders in young and adult classical piano students. *Int Arch Occup Environ Health*. 2008;81(7):855–60.
3. Paarup HM, Baelum J, Holm JW, Manniche C, Wedderkopp N. Prevalence and consequences of musculoskeletal symptoms in symphony orchestra musicians vary by gender: a cross-sectional study. *BMC Musculoskelet Disord*. 2011;12(1):223.
4. Schaefer PT, Speier J. Common Medical Problems of Instrumental Athletes. *Curr Sports Med Rep*. 2012;11(6):316–22.
5. Bragge P, Bialocerkowski A, McMeeken J. A systematic review of prevalence and risk factors associated with playing-related musculoskeletal disorders in pianists. *Occupational Medicine*. 2006;56(1):28–38.
6. Furuya S, Kinoshita H. Organization of the upper limb movement for piano key-depression differs between expert pianists and novice players. *Exp Brain Res*. 2008;185(4):581–93.
7. Furuya S, Aoki T, Nakahara H, Kinoshita H. Individual differences in the biomechanical effect of loudness and tempo on upper-limb movements during repetitive piano keystrokes. *Hum Mov Sci*. 2012;31(1):26–39.
8. Lockwood AH. Medical Problems of Musicians. *N Engl J Med*. 1989;320(4):221–27.
9. Miller G, Peck F, Watson JS. Pain disorders and variations in upper limb morphology in music students. *Med Probl Perform Art*. 2002;17:169–72.
10. Brandfonbrener AG. Musculoskeletal problems of instrumental musicians. *Hand Clin*. 2003;19:231–39.
11. Kumar S. Theories of musculoskeletal injury causation. *Ergonomics*. 2001;44(1):17–47.
12. Russell DL. Establishing a biomechanical basis for injury preventative piano pedagogy. *Recherche en éducation musicale*. 2006;24:105–17.
13. Hamill J, Knutzen KM. *Biomechanical basis of human movement*. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2009.
14. Nordin M, Frankel VH. *Basic biomechanics of the musculoskeletal system*. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2012.
15. Bartel DL, Davy DT, Keaveny TM. *Orthopedic biomechanics: mechanics and design in musculoskeletal systems*. Upper Saddle River: Pearson Prentice Hall Bioengineering; 2006.
16. Britannica. *Human muscle system*. Available at: <http://www.britannica.com/science/human-muscle-system>. Accessed June 12, 2012.
17. Watson AHD. What can studying musicians tell us about motor control of the hand? *J Anat*. 2006;208(4):527–42.

18. Shimose R, Matsunaga A, Muro M. Effect of submaximal isometric wrist extension training on grip strength. *Eur J Appl Physiol*. 2011;111(3):557–65.
19. Gordon NM, Rudroff T, Enoka JA, Enoka RM. Handedness but not dominance influences variability in endurance time for sustained, submaximal contractions. *J Neurophysiol*. 2012;108(5):1501–10.
20. Vøllestad NK. Measurement of human muscle fatigue. *J Neurosci Methods*. 1997;74(2):219–27.
21. Kaniusas E. *Biomedical Signals and Sensors I: Linking Physiological Phenomena and Biosignals*. Heidelberg: Springer-Verlag Berlin Heidelberg; 2012.
22. Konrad P. *ABC of EMG: A Practical Introduction to Kinesiological Electromyography*. 1.4 ed. Scottsdale: Noraxon U.S.A., Inc.; 2005.
23. Ethier CR, Simmons CA. *Introductory Biomechanics: From Cells to Organisms*. Cambridge: Cambridge University Press; 2007.
24. Contessa P, Adam A, De Luca CJ. Motor unit control and force fluctuation during fatigue. *J Appl Physiol*. 2009;107(1):235–43.
25. Criswell E. *Cram's Introduction to Surface Electromyography*. 2nd ed. Sudbury: Jones and Bartlett Publishers; 2011.
26. Merletti R, Parker P, eds. *Electromyography: Physiology, Engineering, and Non-invasive Applications*. Hoboken: John Wiley and Sons; 2004.
27. Conwit RA, Stashuk D, Suzuki H, Lynch N, Schrager M, Metter EJ. Fatigue effects on motor unit activity during submaximal contractions. *Arch Phys Med Rehabil*. 2000;81(9):1211–6.
28. Al-Mulla MR, Sepulveda F, Colley M. A Review of Non-Invasive Techniques to Detect and Predict Localised Muscle Fatigue. *Sensors*. 2011;11(12):3545–94.
29. Beck TW, Ye X, Wages NP. Local muscle endurance is associated with fatigue-based changes in electromyographic spectral properties, but not with conduction velocity. *J Electromyogr Kinesiol*. 2015;25(3):451–6.
30. Fuller JR, Fung J, Côté JN. Time-dependent adaptations to posture and movement characteristics during the development of repetitive reaching induced fatigue. *Exp Brain Res*. 2011;211(1):133–43.
31. Enoka RM, Duchateau J. Muscle fatigue: what, why and how it influences muscle function. *J Physiol*. 2008;586(Pt 1):11–23.
32. de Jesus IRT, Mello RGT, Nadal J. Principal components of frequency domain electromyograms for muscular fatigue analysis. *Conf Proc IEEE Eng Med Biol Soc*. 2010:3519–22.
33. Farina D, Pozzo M, Merlo E, Bottin A, Merletti R. Assessment of average muscle fiber conduction velocity from surface EMG signals during fatiguing dynamic contractions. *IEEE Trans Biomed Eng*. 2004;51(8):1383–93.
34. González-Izal M, Malanda A, Gorostiaga E, Izquierdo M. Electromyographic models to assess muscle fatigue. *J Electromyogr Kinesiol*. 2012;22(4):501–12.
35. Gates DH, Dingwell JB. The effects of neuromuscular fatigue on task performance during repetitive goal-directed movements. *Exp Brain Res*. 2008;187(4):573–85.

36. Johnson PW, Ciriello VM, Kerin KJ, Dennerlein JT. Using electrical stimulation to measure physiological changes in the human extensor carpi ulnaris muscle after prolonged low-level repetitive ulnar deviation. *Appl Ergon.* 2013;44(1):35–41.
37. Kruger ES, Hoopes JA, Cordial RJ, Li S. Error compensation during finger force production after one- and four-finger voluntarily fatiguing exercise. *Exp Brain Res.* 2007;181(3):461–8.
38. Danion F, Latash ML, Li ZM, Zatsiorsky VM. The effect of fatigue on multifinger co-ordination in force production tasks in humans. *J Physiol.* 2000;523(Pt 2):523–32.
39. Danion F, Latash ML, Li ZM, Zatsiorsky VM. The effect of a fatiguing exercise by the index finger on single- and multi-finger force production tasks. *Exp Brain Res.* 2001;138(3):322–9.
40. Gates DH, Dingwell JB. Muscle fatigue does not lead to increased instability of upper extremity repetitive movements. *J Biomech.* 2010;43(5):913–9.
41. Huysmans MA, Hoozemans MJM, van der Beek AJ, de Looze MP, van Dieën JH. Fatigue effects on tracking performance and muscle activity. *J Electromyogr Kinesiol.* 2008;18(3):410–19.
42. Gates DH, Dingwell JB. The effects of muscle fatigue and movement height on movement stability and variability. *Exp Brain Res.* 2011;209(4):525–36.
43. Sakurai T, Toda M, Sakurazawa S, Akita J, Kondo K, Nakamura Y. Study on detection of alternate muscles activity and its transition with muscle fatigue. *2011 International Symposium on IT in Medicine and Education (ITME).* 2011;1:18–22.
44. Kallenberg LAC, Hermens HJ. Behaviour of a surface EMG based measure for motor control: Motor unit action potential rate in relation to force and muscle fatigue. *J Electromyogr Kinesiol.* 2008;18(5):780–8.
45. Farfán FD, Politti JC, Felice CJ. Evaluation of EMG processing techniques using information theory. *Biomed Eng Online.* 2010;9(1):72.
46. Beck TW, Housh TJ, Johnson GO, et al. Electromyographic instantaneous amplitude and instantaneous mean power frequency patterns across a range of motion during a concentric isokinetic muscle action of the biceps brachii. *J Electromyogr Kinesiol.* 2006;16(5):531–9.
47. Barbero M, Merletti R, Rainoldi A. *Atlas of Muscle Innervation Zones.* Milan: Springer; 2012.
48. Davies MR, Reisman SS. Time frequency analysis of the electromyogram during fatigue. *Proceedings of the 1994 20th Annual Northeast Bioengineering Conference.* 1994:93–5.
49. Naik GR, Kumar DK, Arjunan S. Use of sEMG in identification of low level muscle activities: Features based on ICA and fractal dimension. *Conf Proc IEEE Eng Med Biol Soc.* 2009:364–7.
50. Cashaback JGA, Cluff T, Potvin JR. Muscle fatigue and contraction intensity modulates the complexity of surface electromyography. *J Electromyogr Kinesiol.* 2013;23(1):78–83.
51. De Luca CJ. The use of surface electromyography in biomechanics. *J Appl Biomech.* 1997;13:135–63.

52. Wristen B, Jung MC, Wismer AKG, Hallbeck MS. Assessment of muscle activity and joint angles in small-handed pianists. *Faculty Publications: School of Music*. 2006;Paper 7.
53. Zinn M, Zinn M. The application of SEMG feedback in training forearm extensor muscles of an advanced classical pianist: A case study. *Biofeedback*. 2004;32:21–29.
54. Andison C. *EMG-based assessment of active muscle stiffness and co-contraction in muscles with primary and secondary actions at the wrist during piano playing*. Ottawa: Carleton University; 2011. [Masters Thesis].
55. Lowery M, Nolan P, O'Malley M. Electromyogram median frequency, spectral compression and muscle fibre conduction velocity during sustained sub-maximal contraction of the brachioradialis muscle. *J Electromyogr Kinesiol*. 2002;12(2):111–8.
56. Merletti R, Knaflitz M, De Luca CJ. Myoelectric manifestations of fatigue in voluntary and electrically elicited contractions. *J Appl Physiol*. 1990;69(5):1810–20.
57. Bennie KJ, Ciriello VM, Johnson PW, Dennerlein JT. Electromyographic activity of the human extensor carpi ulnaris muscle changes with exposure to repetitive ulnar deviation. *Eur J Appl Physiol*. 2002;88(1-2):5–12.
58. Dimitrova NA, Dimitrov GV. Interpretation of EMG changes with fatigue: facts, pitfalls, and fallacies. *J Electromyogr Kinesiol*. 2003;13(1):13–36.
59. Cifrek M, Medved V, Tonković S, Ostojić S. Surface EMG based muscle fatigue evaluation in biomechanics. *Clin Biomech*. 2009;24(4):327–40.
60. Rogers DR, MacIsaac DT. EMG-based muscle fatigue assessment during dynamic contractions using principal component analysis. *J Electromyogr Kinesiol*. 2011;21(5):811–8.
61. Hollman JH, Hohl JM, Kraft JL, Strauss JD, Traver KJ. Does the fast Fourier transformation window length affect the slope of an electromyogram's median frequency plot during a fatiguing isometric contraction?. *Gait Posture*. 2013;38(1):161–4.
62. MacIsaac D, Parker PA, Scott RN. Non-stationary Myoelectric Signals and Muscle Fatigue. *Methods Inf Med*. 2000;39(2):125–9.
63. Mathur S, Eng JJ, MacIntyre DL. Reliability of surface EMG during sustained contractions of the quadriceps. *J Electromyogr Kinesiol*. 2005;15(1):102–10.
64. Bouillard K, Guével A, Hug F. The electromyographic fatigue threshold is not a valid tool to assess muscle function. *J Electromyogr Kinesiol*. 2011;21(2):229–35.
65. Clancy EA, Farina D, Merletti R. Cross-comparison of time- and frequency-domain methods for monitoring the myoelectric signal during a cyclic, force-varying, fatiguing hand-grip task. *J Electromyogr Kinesiol*. 2005;15(3):256–65.
66. Penn I, Chuang T, Chan R, Hsu T. EMG power spectrum analysis of first dorsal interosseous muscle in pianists. *Med Sci Sports Exerc*. 1999;31(12):1834–8.
67. Bonato P, Roy SH, Knaflitz M, De Luca CJ. Time-frequency parameters of the surface myoelectric signal for assessing muscle fatigue during cyclic dynamic contractions. *IEEE Trans Biomed Eng*. 2001;48(7):745–53.

68. De Luca CJ, Gilmore LD, Kuznetsov M, Roy SH. Filtering the surface EMG signal: Movement artifact and baseline noise contamination. *J Biomech.* 2010;43(8):1573–9.
69. Kong YK, Hallbeck MS, Jung MC. Crosstalk effect on surface electromyogram of the forearm flexors during a static grip task. *J Electromyogr Kinesiol.* 2010;20(6):1223–9.
70. Karlsson S, Yu J, Akay M. Time-frequency analysis of myoelectric signals during dynamic contractions: a comparative study. *IEEE Trans Biomed Eng.* 2000;47(2):228–38.
71. Beck TW, Housh TJ, Johnson GO, et al. Comparison of Fourier and wavelet transform procedures for examining the mechanomyographic and electromyographic frequency domain responses during fatiguing isokinetic muscle actions of the biceps brachii. *J Electromyogr Kinesiol.* 2005;15(2):190–9.
72. De Luca CJ. Myoelectrical manifestations of localized muscular fatigue in humans. *Crit Rev Biomed Eng.* 1984;11(4):251–79.
73. Clancy EA, Bertolina MV, Merletti R, Farina D. Time- and frequency-domain monitoring of the myoelectric signal during a long-duration, cyclic, force-varying, fatiguing hand-grip task. *J Electromyogr Kinesiol.* 2008;18(5):789–97.
74. Cechetto AD, Parker PA, Scott RN. The effects of four time-varying factors on the mean frequency of a myoelectric signal. *J Electromyogr Kinesiol.* 2001;11(5):347–54.
75. González-Izal M, Malanda A, Navarro-Amézqueta I, et al. EMG spectral indices and muscle power fatigue during dynamic contractions. *J Electromyogr Kinesiol.* 2010;20(2):233–40.
76. Zaman SA, MacIsaac DT, Parker PA. Repeatability of surface EMG-based single parameter muscle fatigue assessment strategies in static and cyclic contractions. *Conf Proc IEEE Eng Med Biol Soc.* 2011;2011:3857–60.
77. Karlsson JS, Östlund N, Larsson B, Gerdle B. An estimation of the influence of force decrease on the mean power spectral frequency shift of the EMG during repetitive maximum dynamic knee extensions. *J Electromyogr Kinesiol.* 2003;13(5):461–8.
78. Steinmetz A, Seidel W, Muche B. Impairment of Postural Stabilization Systems in Musicians With Playing-Related Musculoskeletal Disorders. *J Manipulative Physiol Ther.* 2010;33(8):603–11.
79. Bejjani FJ, Kaye GM, Benham M. Musculoskeletal and neuromuscular conditions of instrumental musicians. *Arch Phys Med Rehabil.* 1996;77(4):406–13.
80. Shields N, Dockrell S. The Prevalence of Injuries among Pianists in Music Schools in Ireland. *Med Probl Perform Art.* 2000;15(4):155.
81. Allsop L, Ackland T. *The prevalence of playing-related musculoskeletal disorders in relation to piano players' playing techniques and practising strategies.* Perth: University of Western Australia, Royal Northern College of Music; 2010. Music Performance Research, Special Issue: Music and Health.
82. Quarrier NF. Is hypermobility syndrome (HMS) a contributing factor for chronic unspecific wrist pain in a musician? If so, how is it evaluated and managed? *Work.* 2011;40(3):325–33.

83. Fagarasanu M, Kumar S, Narayan Y. Measurement of angular wrist neutral zone and forearm muscle activity. *Clin Biomech*. 2004;19(7):671–7.
84. Oikawa N, Tsubota S, Chikenji T, Chin G, Aoki M. Wrist Positioning and Muscle Activities in the Wrist Extensor and Flexor During Piano Playing. *Hong Kong Journal of Occupational Therapy*. 2011;21(1):41–6.
85. Altenmüller E, Kopiez R. Suffering for Her Art: The Chronic Pain Syndrome of Pianist Clara Wieck-Schumann. *Front Neurol Neurosci*. 2010;27:101–18.
86. Lai CJ, Chan RC, Yang TF, Penn IW. EMG changes during graded isometric exercise in pianists: comparison with non-musicians. *J Chin Med Assoc*. 2008;71(11):571–5.
87. De Luca CJ, Sabbahi MA, Roy SH. Median frequency of the myoelectric signal. *Eur J Appl Physiol Occup Physiol*. 1986;55(5):457–64.
88. National Institutes of Health. *The Brain: Our Sense of Self*. Colorado Springs: BSCS; 2005.
89. Zaza C, Farewell VT. Musicians' playing-related musculoskeletal disorders: An examination of risk factors. *Am J Ind Med*. 1997;32(3):292–300.
90. Fry HJ. Prevalence of overuse (injury) syndrome in Australian music schools. *Br J Ind Med*. 1987;44(1):35–40.
91. Redmond M, Tiernan AM. Knowledge and Practices of Piano Teachers in Preventing Playing-related Injuries in High School Students. *Med Probl Perform Art*. 2001;16(1):32.
92. Lederman RJ. Neuromuscular and musculoskeletal problems in instrumental musicians. *Muscle Nerve*. 2003;27(5):549–61.
93. Ranelli S, Smith A, Straker L. Playing-related musculoskeletal problems in child instrumentalists: The influence of gender, age and instrument exposure. *International Journal of Music Education*. 2011;29(1):28–44.
94. Sakai N. Hand pain attributed to overuse among professional pianists. *Med Probl Perform Art*. 2002;17:178–80.
95. Sakai N, Liu MC, Su FC, Bishop AT, An KN. Hand Span and Digital Motion on the Keyboard: Concerns of Overuse Syndrome in Musicians. *J Hand Surg Am*. 2006;31(5):830–5.
96. Sakai N, Shimawaki S. Measurement of a number of indices of hand and movement angles in pianists with overuse disorders. *J Hand Surg Eur Vol*. 2010;35(6):494–8.
97. Grieco A, Occhipinti E, Colombini D, et al. Muscular effort and musculoskeletal disorders in piano students: electromyographic, clinical and preventive aspects. *Ergonomics*. 1989;32(7):697–716.
98. Yoshie M, Kudo K, Murakoshi T, Ohtsuki T. Music performance anxiety in skilled pianists: effects of social-evaluative performance situation on subjective, autonomic, and electromyographic reactions. *Exp Brain Res*. 2009;199(2):117–26.
99. Rojas M, Mananas MA, Muller B, Chaler J. Activation of Forearm Muscles for Wrist Extension in Patients Affected by Lateral Epicondylitis. *Conf Proc IEEE Eng Med Biol Soc*. 2007:4858–61.

100. Delsys® Incorporated. Bagnoli™ EMG System: User's Guide. [Internet]. October 2011.
[http://www.delsys.com/Attachments_pdf/Bagnoli%20Users%20Guide%20\(MAN-004-1-3\).pdf](http://www.delsys.com/Attachments_pdf/Bagnoli%20Users%20Guide%20(MAN-004-1-3).pdf).
101. Weiss LD, Silver JK, Weiss JM. *Easy EMG: A Guide to Performing Nerve Conduction Studies and Electromyography*. Edinburgh: Butterworth-Heinemann; 2004.
102. Determination of Sensor Location. Available at: www.seniam.org. Accessed May 2012.
103. McDonald JH. *Handbook of Biological Statistics*. 3rd ed. Baltimore: Sparky House Publishing; 2014.
104. Moore DR, Burgomaster KA, Schofield LM, Gibala MJ, Sale DG, Phillips SM. Neuromuscular adaptations in human muscle following low intensity resistance training with vascular occlusion. *Eur J Appl Physiol*. 2004;92(4-5):399–406.
105. Talebinejad M, Chan ADC, Miri A. Fatigue estimation using a novel multi-fractal detrended fluctuation analysis-based approach. *J Electromyogr Kinesiol*. 2010;20(3):433–9.
106. Talebinejad M, Chan ADC, Miri A. A Lempel–Ziv complexity measure for muscle fatigue estimation. *J Electromyogr Kinesiol*. 2011;21(2):236–41.
107. American Society for Surgery of the Hand. *Wrist Joint Movements*. Available at: <http://www.assh.org/handcare/hand-arm-anatomy>. Accessed June 12, 2012.