Evaluation of Piano-Related Injuries using Infrared Imaging

by

Safaa Mohamed

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs

in partial fulfillment of the requirements for the degree of
Master of Applied Science in Biomedical Engineering

(Ottawa –Carleton Institute for Biomedical Engineering (OCIBME))

Department of Systems and Computer Engineering

Carleton University

Ottawa, Ontario, Canada, K1S 5B6

April 2011

Your file Votre référence
ISBN: 978-0-494-81667-7
Our file Notre référence
ISBN: 978-0-494-81667-7

The undersigned recommend to

the Faculty of Graduate and Postdoctoral Affairs

acceptance of the thesis

Evaluation of Piano-Related Injuries using Infrared Imaging

submitted by

Safaa Mohamed, B. Electrical Engineering

in partial fulfillment of the requirements for

the degree of Master of Applied Science in Biomedical Engineering

Chair, Howard Schwartz, Department of Systems and Computer Engineering

Thesis Supervisor, Dr. Monique Frize

Carleton University

April 2011

Abstract

Playing the piano is a repetitive task that involves the use of the hands and the arms. Pain related to piano-playing is the result of extending the tissues and ligaments of the hands and arms beyond their mechanical tolerance. Infrared imaging records the skin temperature and produces a thermal map of the imaged body part; small variations in the skin temperature could be the sign of inflammation or stress on the tissues. In this thesis we correlated heat to pain related to piano-playing; we used statistical analysis to examine the difference in heat temperature between pianists with pain related to piano-playing and pianists without pain related to piano-playing. We found that there is a statistically significant difference in hand temperature between the two populations. In addition, pianists with pain have higher hand temperatures relative to their arms. These findings may lead to earlier detection and easier diagnosis of repetitive stress injuries.

Acknowledgments

I would first like to thank my supervisor, Dr. Monique Frize, for her guidance and mentorship.

I would like to thank Dr. Gilles Comeau, for allowing me to use the piano lab at the University of Ottawa. Also, I would like to thank Kimberley Sundell at the piano lab for her accommodations to my schedule.

Thanks to all the participants who made it possible to finish my experiment.

Thank you to Dr. Christophe Herry and Michael Grzesina for their invaluable help and advice.

A big thank you to Dr. David Mould for discussing with me how to improve my thesis and for his support and encouragement. Another big thank you to Benny, Crane, Jasper, and Jules for their unwavering support throughout the process.

Thank you to Dr. Rafik Goubran for his encouragement to finish.

Thank you to Trevor Lewis, my former employer at the Undergraduate Recruitment Office, for accommodating my thesis work and for his continuing interest in my thesis progress.

Thank you to my mother, Ahlam Amer, and my sister Amal, for their long distance support and encouragement.

Finally, thank you to all my family and friends overseas and in Canada for their support.

Contents

List of Tables

List of Figures

Chapter 1

Introduction & Background

1.1 Motivation

Skill at playing the piano is achieved by practicing the musical notes over and over again to gain the ability to play correctly or master the piano. Piano-playing related injuries, known as overuse syndrome, is a type of musculoskeletal disorder that is caused by motion repetition and can result in trauma to the muscles and joints of the hand, wrist and elbow (Heming 2004, Bragge 2006).

Many terms have been used to describe musculoskeletal disorders such as overuse syndrome, repetitive strain injuries, and cumulative trauma disorders. Some argue that the term overuse is not the right term since the pain is due to misuse rather than overuse. Others argue that the term overuse is the right term and other terms are general terms that do not reflect the condition (Dawson 2001). Others recommend the term work- related musculoskeletal disorders since playing a musical instrument counts as work. Piano-related musculoskeletal disorder is a music specific term that is derived from work related musculoskeletal disorders (PRMD) (Bragge 2006). PRMD includes overuse syndrome, tendonitis and tenosynovitis, nerve compression syndrome, and focal dystonia. In this thesis we are more concerned with pain due to overuse syndrome or repetitive strain injuries. Hence we are going to use the term overuse syndrome.

The hand, wrist, and arm play a significant role in lots of everyday activities including playing the piano. These regions have a large number of tendons and are subject to overuse syndrome as a result of excessive repetition of motion while playing the piano (Pecina and Bojanic 2004). Ligaments and tendons can withstand a considerable load within certain tolerance. Overuse syndrome is the result of extending the ligaments and tendons of the hands and arms beyond their tolerance by excessive motion repetitions, as in the case of practicing the piano. Overuse syndrome is characterized by pain and tenderness in the affected areas (Pecina and Bojanic 2004, Tubiana and Amadio 2000).

Overuse syndrome is hard to diagnose because there are no apparent physical signs. It is not clearly understood why the disorder may affect one hand but not the other, or why it may affect both hands. Also, the cause of the swelling of some parts may seem unclear. The areas of tenderness vary from time to time; sometimes the pain begins after the activity but does not appear during the activity, making it difficult to reproduce the symptoms (Heming 2004, Tubiana and Amadio 2000).

Work related musculoskeletal disorders may cause pain and in extreme cases might lead to loss of employment because the worker is no longer able to perform their physical tasks. Most existing studies were done on office workers and computer users although musicians are also at high risk (Zaza 1998). Instrumental musicians, including teachers, students, and especially professional performers, are at high risk of developing musculoskeletal disorders (Lederman 2003). It has been found that stringed instrument players are more likely to suffer from overuse injuries than wind instrument players, with a ratio of 3:1 (Heming 2004). Overuse syndrome is a common medical problem among pianists (Fry 1988).

Studies were done to determine the prevalence of overuse syndrome among musicians. One study found that among 66 pianists, 28 (16 women and 12 men) suffered from overuse syndrome, mainly affecting the wrist (Smet 1998). A second study was conducted with 59 questionnaires on musicians who played a variety of instruments, including flute, trumpet, and piano. The study found that 70% of the participants have or had an injury related to playing their instrument. One third of the participants indicated that they stopped playing their instrument for a while due to their injuries (Heming 2004).

In 1987, Fry conducted a general study in seven Australian performing music schools and reported that overuse syndrome appeared in 9.3% of the performers of various instrument types such as keyboard, woodwind, and string instruments. Half of the students who suffered from overuse syndrome had pain in their hands and wrists. Then Fry conducted a more detailed study in two of the seven schools and found that the percentage of the disorder was 13% in one school and 21 % in the second school. In 1998, Zaza did a comprehensive survey on previous studies of overuse syndrome and found that the reported prevalence had a range of 26%-93% among pianists.

Some papers reported that the duration of the practice session is a factor in increasing the injuries. Since most musicians are self employed and might have more than one job at a time, overuse syndrome might have devastating effects on them and leave them with no employment (Heming 2004, Shields and Dockrell 2000, Zaza 1998).

1.2 Thesis Objective and Problem Statement

Playing the piano is a complicated technique that requires hours of practicing, and involves a broad range of movements from pressing down the keys to using the whole body in playing scales, arpeggios, and chords. Practicing to achieve the independent movement of each finger can result in overusing the forearm muscles. Movement requires muscles flexion, extension, and rotation. Wrong technique in piano-playing can result in overuse syndrome (Heming 2004); it is easy to build up muscle tension while playing the piano and focusing on achieving the right sound (Pearl 2008).

The position of the wrist plays a major role in playing the piano because finger extension and flexion cannot be accomplished without the support of the wrist. Therefore, it is important to put the arm in the right position to avoid muscle strain. Also, good posture minimizes stress with the repetitive motion of the fingers. The long term effect of poor playing technique is not well known (Sandor 1981, Tubiana and Amadio 2000). Infrared imaging is a good way to study heat associated with overworked muscles because it measures the body's heat and produces a thermal image showing the hot and cold areas (Burnay et al. 1988).

The main objective of this thesis is to evaluate the use of infrared imaging as a tool to investigate pain induced by piano-playing known as overuse syndrome or repetitive strain injury. We would like to show that there is a correlation between heat and pain due to piano-playing, and if possible show that infrared imaging can show the difference in hand and arm temperature measurements between pianists with pain and pianists without pain related to piano-playing. The second objective is to show the difference in temperature changes over time between pianists with pain and pianists without pain. The third objective is to identify whether the hands, the lower arm, or the upper arm would be the best region to study pain due to piano-playing. The fourth objective is to identify those with poor piano-playing techniques by comparing the different heat patterns for the hand, lower arms, and upper arms for the same subject during piano-playing.

Warm-up exercises that are aimed towards improving the flexibility of the fingers and the hands have been recommended before starting to play the piano (Pearl 2008). Some piano players do not do warm-up exercises while others do. In this thesis we would like to evaluate the effect of warm-up exercises on piano players by having them respond to a simple questionnaire. In this way, we hope to determine if pianists who practice warm-up techniques are less likely to suffer from overuse syndrome or pain related to playing the piano.

1.3 Outline

The second chapter is the literature review, describing medical thermal infrared imaging, its applications in medicine, and the technology behind it. It also gives a brief review on hand and arm anatomy, physiology of pain, and what has been done in studying piano-playing related injuries. Chapter three is the methodology chapter, describing in detail the process of obtaining the data, ethics approval, and the process of recruiting the volunteers. It contains a description of the infrared camera that was used in this research and the protocol that was followed to obtain the images. It also explains the analysis of the infrared images. Chapter four describes the results and our findings. Chapter five provides the conclusion, identifies contributions, and recommends future work that can be done to complement the research outcome.

Chapter 2

Literature Review

There are two main components in this chapter. The first component is the prevalence of injuries related to piano-playing. The second component describes the advances in infrared technology as a tool to assess pain, as well as to diagnose breast cancer and arthritis.

2.1 Hand and Arm Anatomy:

The upper limb or the upper extremity consists of thirty bones: the humerus in the arm, the radius and the ulna in the forearm and, the eight carpals in the carpus or the wrist, the five metacarpals in the metacarpus or the palm, and the fourteen phalanges (the digits bones) in the hand (Campbell et al. 2006). The upper extremity is shown in figure 2.1.

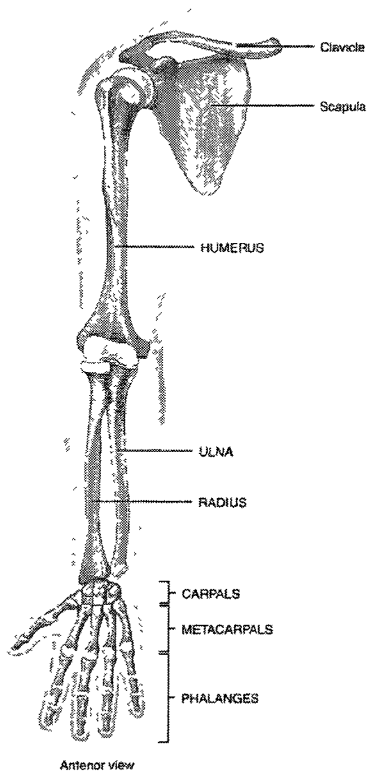


Figure 2.1: The bones of the upper limb (upper extremity). Source: Tortora and Derrickson 2006, p. 253.

There are three types of joints: fibrous joints, cartilaginous joints, and synovial joints. In fibrous joints, the bones are connected to each other by connective tissues that mainly consist of collagen fibres. In cartilaginous joints, the bones are connected to each other by cartilage. In synovial joints, the bones are connected to each other by a synovial cavity that is enclosed in a capsule. Synovial joints are the most common joints in the human body and include the ball and socket joint, the hinge joint, the pivot joint, the condyloid joint, and the sadle joint (Tortora and Derrickson 2006).

The ball and socket joints are located at the shoulder joining the humerus to the shoulder girdle and allow rotation of the arm and movements in all three axes or directions. The ball and socket joint consists of a ball shaped bone fitting into a cup like bone. The ball and socket joint allows extension, flexion, abduction, adduction, circumduction and rotation (Tortora and Derrickson 2006).

The hinge joint is located at the elbow and allows movement in a single direction. In the hinge joint, the convex surface of one bone fits into to the concave surface of the other one, where one bone is fixed and the other one moves around an axis. The hinge joint allows extension and flexion (Tortora and Derrickson 2006).

The pivot joint is located at the elbow and allows rotation of the forearm at the elbow; it allows us to move our hands from side to side. The pivot joint consists of a rounded surface bone fitting into a ring made of bones and ligaments (Tortora and Derrickson 2006).

The condyloid joint is located at the wrist and at the metacarpophalangeal joints (second, third, fourth, and fifth digits); it allows movement around two axes. It consists of convex oval shaped bone fitting in the depression of another bone. The condyloid joint allows for extension, flexion, abduction, abduction, and circumduction (Tortora and Derrickson 2006).

The saddle joint is similar to the condyloid joint, but it allows more free movements. It is located between the carpus (the wrist) and the metacarpal of the thumb, allowing movement in two directions. The saddle joint consists of one bone fitting into a saddle- like shaped bone; it allows extension, flexion, abduction, adduction and circumduction (Tortora and Derrickson 2006).

Muscles are connected to bones by tendons and act with bones to produce movement. Muscles can contract or shorten. The relaxation of the muscles is a passive process. All animals have pairs of antagonistic muscles that act opposite to each other to produce movement. There are a variety of muscles in the forearm that are responsible for moving the wrist, hand, fingers and thumb. There are two main muscle groups in the forearm, the anterior or the flexor muscles and the posterior or the extensor muscles. The flexor muscles start at the humerus and insert on the carpals, metacarpals and phalanges. The posterior muscles start at the humerus and insert into metacarpals and the phalanges (Campbell et al. 2006, Tortora and Derrickson 2006). Figure 2.2 shows the muscles of the arm; biceps muscles (forearm flexor) contraction would result in raising the arm, while a triceps muscle (forearm extensor) contraction would result in lowering the arm. Muscle fatigue can happen as a result of overworked muscles such that the muscles stop contracting. Therefore, there should be a balance between training to strengthen the muscles, and relaxing the muscles (Campbell et al. 2006).

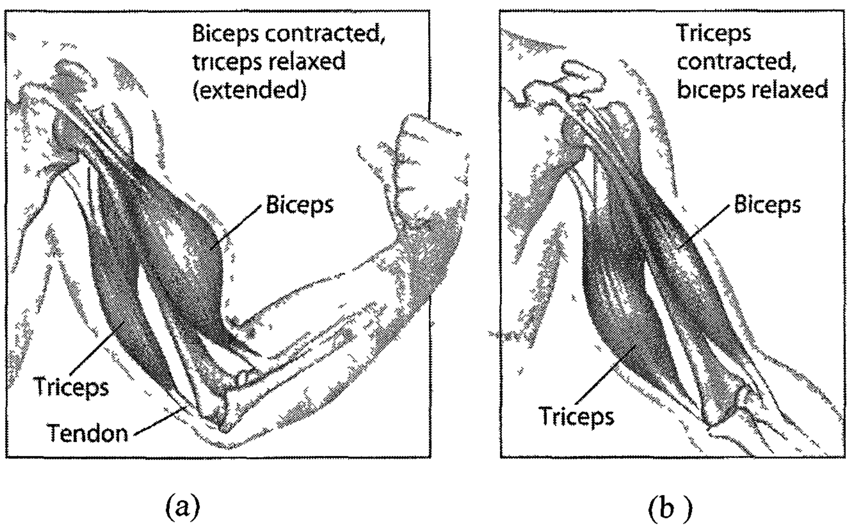


Figure 2.2: Arm muscles (a) biceps muscles (forearm flexor) contraction would result in raising the arm, (b) triceps muscles (forearm extensor) contraction would result in lowering the arm. Source: Campbell et al. 2006, p. 613.

2.2 Physiology of Pain

Pain is a universal subjective term that depends on the individual experience and perception. Pain severity, duration, and visible signs differ from one person to another. There are many sources of pain such as trauma, stress, or inflammation. A person can experience pain from more than one source at the same time. Usually people will try to manage pain on their own and only seek medical care for their pain when the pain starts interfering with their daily routine or becomes uncontrollable (Laccetti and Kazanowski 2008).

Pain can be acute or chronic and is described by various terms such as pressure, burning, aching, or dull. Acute pain occurs with identifiable factors, can be constant or intermittent, and it varies in type and severity. Acute pain does not describe the severity in pain but rather describes the duration of the pain. Pain that can be resolved or controlled in less than six months is considered to be acute pain, while pain that is resolved or controlled in more than six months is considered to be chronic pain (Laccetti and Kazanowski 2008, Wall 1999).

Acute pain and chronic pain differ in the symptoms. Acute pain is brought on by specific activities resulting in preventing the completion of the activity or the task that causes the pain. This pain can be avoided by avoiding the cause of the pain. A person who suffers from acute pain may become agitated and anxious and usually experience a change in vital signs such as increase in respiration rate or blood pressure (Laccetti and Kazanowski 2008).

On the other hand, chronic pain is not predictable and the end point is not known. The person usually does not experience changes in vital signs. Chronic pain diagnosis depends on the health care provider's assessment and is usually undertreated because there is no standard testing for pain. Treatment of chronic pain is usually accomplished by prescribing drugs (Laccetti and Kazanowski 2008, Merskey and Bogduk1994).

The feeling of pain involves the central nervous system and the peripheral nervous system. Nociceptors are specialized nerve cells found in the skin, muscles and connective tissues and act as sensory receptors that respond to injuries. A chemical mediator called prostaglandins is released as a response to the stimulation causing nociceptors to fire the pain signal to the spinal cord (Laccetti and Kazanowski 2008, Merskey and Bogduk1994, Wall 1999).

There are various types of pain such as superficial pain, visceral pain, somatic pain, and neuropathic pain. Superficial pain is a localized pain as a result of direct injuries to the skin such as scraping, abrasion or burns. Visceral pain is a deeper type of pain than the superficial pain such as pain in the abdominal or in the thoracic area. Somatic pain is a localized pain associated with trauma or a specific activity such as playing the piano. It arises in muscles, bones, joints, tendons, and ligaments and it ranges from being dull to sharp. It can be constant or intermittent and may indicate the early warning signs of a progressive condition that can be prevented by early intervention.

Neuropathic pain or neuroleptic pain results from direct damage to the peripheral or central nervous system. It ranges from mild to severe and it is usually continuous not intermittent. It is characterized by a burning sensation that is accompanied by feeling heat or cold, tingling and numbness, or even paralysis. Neuropathic pain may become a chronic pain that is hard to manage. Since there is often no visible damage, people who complain from this type of pain might be overlooked and considered complainers by health care professionals. Treatments including anti-seizure medication and surgeries are used to control the pain (Laccetti and Kazanowski 2008, Wall 1999).

2.3 The Human Skin and Thermoregulation

Studying skin temperature is a complex process. Any changes in the person's pathology may result in a change of this pattern. Infrared imaging can be used to investigate these changes if the changes are big enough to be detected by infrared cameras. Diseases may result in changing the heat pattern or changing the temperature range in an abnormal way without changing the heat distribution pattern. The heat pattern might be changed due to other factors such as taking medication or being under thermal or mechanical stressors. Therefore infrared thermography is a good tool to monitor disease progress or the effective of the treatment (Houdas 1982).

Skin temperature is affected mainly by blood perfusion; therefore, diseases that affect blood circulation, especially in the extremities, can be studied using infrared thermography. The skin local temperature increases by increasing blood flow to a specific area and decreases by decreased blood flow. An arterial obstruction or cyst will reduce blood flow while an inflammatory disease will increase the skin temperature at the affected area (Jones 1998).

Medical infrared thermal imaging or thermography is a non-invasive method that captures the body's thermal energy and transfers it to a thermal map showing the distribution of body heat (Jones 1998). Medical infrared imaging does not produce any radiation and therefore has no known risks associated with it (Jones 1998, Jones 2002), which makes it a good choice for a long term study of inflammatory diseases or pain (Ring 1994, Devereau at al. 1985).

The human skin has a temperature that ranges from 300 K to 315 K and emits an electromagnetic wave energy that reaches a peak around 9.5 μm wavelength at which the body emits the maximum energy. The skin emissivity varies with the wavelength; the skin emissivity is low in the visible light range (0.4-0.8μm) and is close to 1 in the infrared range around 9.5 μm. Human skin also has an absorption coefficient close to one at 9.5 μm range. The radiation emitted by the skin's surface can be detected by infrared cameras (Houdas 1988).

2.4 Physics of Thermal Radiation

Infrared is an electromagnetic wave that has a wavelength longer than visible light and shorter than microwave (Burnay et al. 1988). The electromagnetic spectrum is illustrated in figure 2.3. Infrared radiation lies outside the visible range of the human eye but can be detected by infrared cameras that are equipped with detectors that sense the changes in thermal energy at those wavelengths. All bands of the electromagnetic spectrum obey the same radiation laws (Burnay et al. 1988, Diakides and Bronzino 2008, Schlessinger 1995).

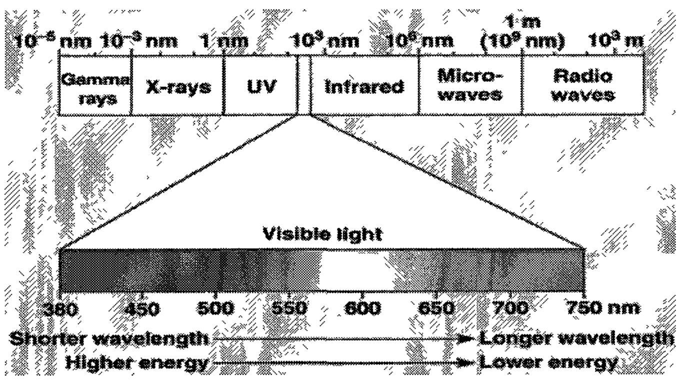


Figure 2.3: The electromagnetic spectrum. Source: www.infraredservices.net/introduction.htm

The infrared region as shown in figure 2.4 is divided into bands that have different wavelengths; the *near infrared* (0.75–3 μm), the *middle infrared* (3–6 μm), the *far infrared* (6–15 μm), and the *extreme infrared* (15–100 μm). The end of the short wavelength is bounded by the visible light region and the long wavelength end is bounded by the microwave radio wavelengths. Infrared cameras operate in the near infrared band (FLIR Systems 2004).

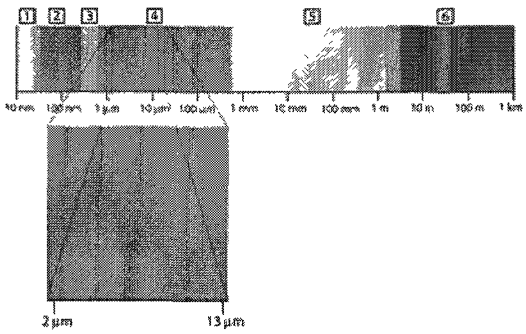


Figure 2.4: Infrared regions, the near infrared, the middle infrared, the far infrared, and the extreme infrared. Source: FLIR Systems 2004.

All objects that have a temperature above absolute zero Celsius or -273.15 Kelvin emit electromagnetic radiation that can be captured by infrared cameras (Burnay et al. 1988, Jones 1998, Jones 2002, Diakides and Bronzino 2008, Schlessinger 1995). The emissivity of an object is the total energy that is radiated from the object surface to its surroundings. Therefore, the temperature of a surface can be measured if we know the emissivity of a surface.

2.4.1 Black Body Radiation

A black body is any object that absorbs all incident radiation at any wave lengths from all directions and radiates in a continuous spectrum. The emitted radiation depends on the wavelength and temperature (Diakides and Bronzino 2008, Schlessinger 1995), and is governed by Planck's radiation Law (Burnay et al. 1988, Diakides and Bronzino 2008, Schlessinger 1995):

$$W_{\lambda b} = \frac{2\pi hc^2}{\lambda^5 (e^{hc/\lambda kT} - 1)} \times 10^{-6} [Watt/m^2, \mu m] \qquad (2.1)$$

Where:

$W_{\lambda b}$: the black body radiant emittance at wavelength λ λ: the wavelength in μm

T: absolute Temperature in Kelvin (K)

h: Plank's constant = 6.62 x 10 $^{-34}$ Joule sec

c: velocity of light = 3 x 10^8 m/ s

k: Boltzmann's constant = 1.4 x 10 $^{-23}$ Joule/K

By plotting Planck's radiation Law for different temperature values, we will get different curves for different temperature values. At λ=0, the emittance is zero then it increases until it reaches the maximum at λ_{max} then it decreases in value again until it approaches zeros as shown in figure 2.5.

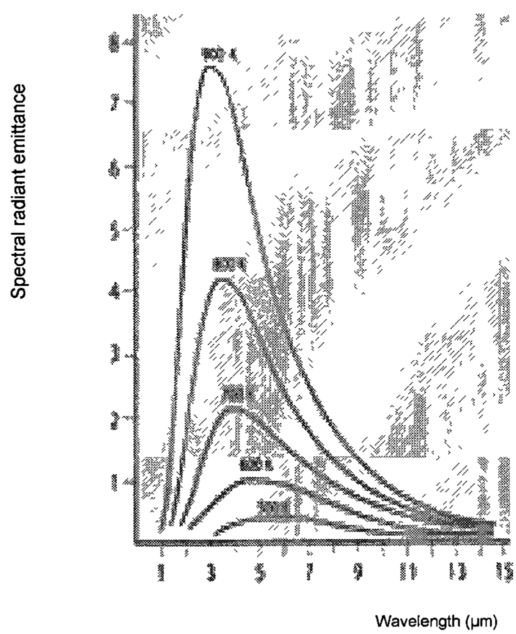


Figure 2.5: Planck's radiation law. Different curves at different wavelength (λ) values; the higher the temperature, the shorter the wavelength. Source: Burnay et al. 1988.

2.4.2 Stefan-Boltzmann's law

Stefan-Boltzmann's law states that "the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature." (Burnay et al. 1988).

The total emittance W_b for the black body is given by:

$$W_b = \sigma T^4 \text{ [watt/m}^2\text{]} \tag{2.2}$$

Where:

σ: the constant of proportionality, called Stefan-Boltzmann constant.

T: the absolute temperature.

The area under Planck's law curve represents Stefan-Boltzmann's law, i.e. Stefan-Boltzmann's law is the integration of Planck's radiation law from $\lambda = 0$ to $\lambda = \infty$.

2.5 Infrared Materials and Detectors

The basic principle behind infrared thermography is that if the surface emissivity is known, then the temperature of that surface can be determined. A typical infrared camera has lenses that collect incident radiation and deposit it to a detector. Detectors are the elements within the infrared cameras that are responsible for sensing the infrared radiation or heat. Therefore the type of the detector and its thermal sensitivity are what governs the success of the infrared camera in recording an accurate measurement of the body's temperature. To achieve a high thermal sensitivity and a fast response time, infrared cameras are equipped with an array of detectors (Jones 1998, Jones 2002).

There are two main types of detectors: thermal detectors and photon detectors (Burnay et al. 1988, Schlessinger 1995, Diakides and Bronzino 2008). We will describe each in turn.

2.5.1 Thermal Detectors

The absorbed energy causes the detector's temperature to increase. The increase in temperature is sensed by a bolometer, which is a device that has an element that changes its resistance with the change in temperature. The change in resistance causes the current through the bolometer element to change, and the current is then converted to an output signal by a bias circuit (Diakides and Bronzino 2008).

2.5.2 Photon Detectors

Photon detectors are semiconductors that convert the incident photons into free electrons. The incident photons interact with the semiconductors' electrons that are in the binding states. The incident photon must have energy that is greater than or equal to the electron binding energies to be able to excite the electrons into the conducting state (Burnay et al. 1988, Schlessinger 1995).

There are two types of photon detectors: photoconductive and photovoltaic detectors. Photoconductive detectors work by measuring the current caused by the excited electrons, while photovoltaic detectors work by collecting the excited electrons in a diode (Diakides and Bronzino 2008).

2.5.3 Photoconductive Detectors

The electrons in the binding state are excited to the mobile state when the incident photons are absorbed within the detector material (Diakides and Bronzino 2008). Figure 2.6 shows a photoconductive detector that has a width W, length L, and thickness t. When the photon flux φ_0 is absorbed by the detector material, the electrons are excited to the mobile state and an electrical current will be produced when a bias voltage E is applied across the detector

(Diakides and Bronzino 2008). The higher the photon flux energy, the more electrons will be released and the higher the photocurrent. Therefore photocurrent is directly proportional to the number of incident photons (Burnay et al. 1988, Diakides and Bronzino 2008).

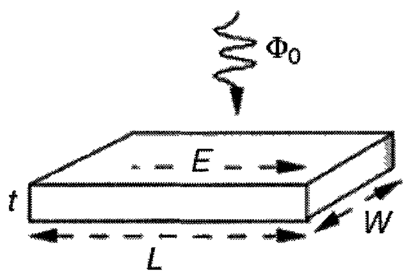


Figure 2.6: Abstract representation of photoconductive detector. Source: Diakides and Bronzino 2008).

2.5.3 Photovoltaic Detectors

Photovoltaic detectors are also known as photodiodes or junction detectors because they use diode junctions to collect the photoexcited electrons. They are the most used detectors in infrared cameras (Diakides and Bronzino 2008). The incident photons create an electron hole pair in the n-type side. The hole diffuses to the p-type side of the detector creating a photocurrent. The p-type side of the detector material is connected to an indium bump that is connected to an amplifier in a readout circuit that stores the signal until it is conveyed to a display (Burnay et al, 1988, Schlessinger 1995, Diakides and Bronzino 2008).

2.6 Measuring Formula for FLIR Infrared Camera

An infrared camera receives radiation not only from the object to be imaged but from the surrounding environment. Assuming that the infrared camera receives radiation with power W from a black body source, then the generated signal (U_{source}) after travelling a certain distance is proportional to the power W.

$U_{source} = C\ W$ (2.3)

Where:

C: constant.

Assuming that the temperature reflected from all sources is the same and the surrounding emittance is equal to 1 according to Kirchhoff's law, then we can drive the emission formulas for the object and atmosphere as follows (FLIR Systems 2004):

- Object emission= $\varepsilon\ T\ W_{obj}$ (2.4)

  Where:

  ε: the object emissivity

  T: the atmosphere transmittance

  W_{obj}: the object radiation power

- Ambient sources reflected temperature= $(1-\varepsilon)\ T\ W_{ref}$ (2.5)

  Where:

  $(1-\varepsilon)$: the object reflectance

  W_{ref}: the power of the reflected radiation.

- The atmosphere emission= $(1-T)\ T\ W_{atmosphere}$ (2.6)

  Where:

  (1-T): the atmosphere emittance.

$W_{atmosphere}$: the power of the reflected atmospheric radiation

- The total radiation power= $\varepsilon\, T\, W_{obj} + (1\text{-}\varepsilon)\, T\, W_{ref} + (1\text{-}T)\, T\, W_{atmosphere}$ (2.7)

By multiplying the last equation by constant C and replacing the term C W by U, we get the following equation:

$$U_{total} = \varepsilon\, T\, U_{obj} + (1\text{-}\varepsilon)\, T\, U_{reflected} + (1\text{-}T)\, T\, U_{atmosphere} \quad (2.8)$$

By solving the equation for U_{obj}, we get:

$$U_{object} = (1/\,\varepsilon\, T)\, U_{total} - ((1\text{-}\varepsilon)/\,\varepsilon)\, U_{reflected} - ((1\text{-}T)/\,\varepsilon\, T)\, U_{atmosphere} \quad (2.9)$$

This equation is the one used in all FLIR cameras to measure infrared radiation for an object (FLIR Systems 2004).

2.7 Injuries Prevalence and Risk Factors

Musicians' pain related to their instrument playing had been ignored until the last decade (Alford 1996). In 1996, Alford and Szanto conducted a survey that involved members of the New York State Music Teachers Associations and found that more than half of the performing pianists had suffered from some sort of physical injuries or pain related to their piano-playing. There is no permanent cure for the pain associated with playing the piano once it has developed therefore, it is important to understand the factors behind the injuries in order to prevent them.

Playing the piano requires intense practice and emphasizes speed and accuracy. These intense levels of practice expose pianists to potential piano related musculoskeletal disorders (PRMDs) of the upper extremities (Bragge 2006). Since playing the piano requires physical strength, people with small hands might be at higher risk than people with bigger hands for developing musculoskeletal disorders. The great demands placed on the hands and fingers to achieve the desired sound put the hands and the fingers under great strain. The number of available concert piano jobs has decreased leading to higher competition and increase in the standards of their performance. A high level of performance requires long hours of practice because pianists are under great stress to produce the perfect musical notes. Also, a poor piano-playing technique can be transferred from piano teachers to students. Piano teachers are more focused on teaching their students how to play the piano rather than teaching them the biomechanics behind playing the piano. In addition, some musicians believe that pain comes with being skilled at playing the piano. All of the above are risk factors that contribute to excessive muscle pain and fatigue (Alford 1996).

Some researchers tried to quantify the prevalence of the injuries associated with playing the piano. For example, Smet et al. (1998) recruited 66 pianists in total, 33 women and 33 men. The men started playing between 5 and 18 years old and the women started playing between the age of 5 and 13 years old. The age range of the participants was from 18-32 years. The volunteers completed questionnaires about their playing routine and identified whether they suffered from musculoskeletal problems due to piano-playing or not. The hand size of each volunteer was also measured. Smet et al. found that factors such as the starting age, duration of practice, warm-ups, stretching, and playing another instrument did not correlate with developing overuse syndrome. However, he found that people with smaller hands were more prone to overuse syndrome. Other factors that contribute to overuse syndrome are the playing style including loud playing and forceful playing (Hoppmann and Reid 1995, Wolf et al. 1993).

The most common sites of injuries due to piano-playing are the upper extremities (the wrist, the hand, and the forearm) and the back (Bejjani et al. 1996, Vant 2007). Many studies have found that playing-related injuries are more common among pianists, guitarists, and string players than in woodwind players (Bragge 2006). A study by Bengston and Shutt (1992) found that the most common diagnoses for pianists are overuse syndrome, tendinitis, focal dystonia, and nerve entrapment. In a study that was carried-out on musicians, including 75% pianists, Hochberg et al. (1983) found that the most common problems are tendon and joint inflammatory disorders.

Rest is the most common way to treat overuse syndrome. In cases of severe injuries, the musicians are advised to stop playing the instrument for a while, or to reduce the practice time if the injuries are less severe. Evaluating the pianist's posture, movement and the playing technique is usually done in an attempt to reduce or prevent further injuries (Hoppmann and Reid 1995, Vant 2007).

2.8 Thermal Imaging System Development

The history of infrared imaging started in 1800, when Sir William Herschel detected rays beyond the visible red region on the spectrum. In 1840, his son John made the first thermal image from sunlight and called it a thermogram (Ring 2004, Ring 2007).

Thermal imaging systems were developed in the 1940s and were used in industry and medicine in 1959 to image an arthritic joint. The imaging system was slow and each image took 3-4 minutes to acquire (Ring 2004).

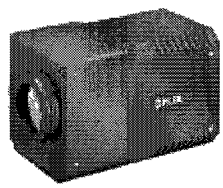
A new generation of thermal imaging systems was developed in the 1960s and 1970s. Computers became part of the imaging systems in the mid to late 1970s to store and display colored images. This was the start of the quantifying process of thermal images (Ring 2004, Ring and Ammer 2000).

Historically, there have been two types of infrared imaging systems. The first type requires direct contact with the skin through a liquid crystal plate that is placed on the area of interest to measure its temperature. The first type had a serious problem because the temperature recording can be affected by the contact of the liquid crystal plate with the skin. The second type does not require direct contact with the skin, and instead works by using detectors that detect the heat emitted from the human body. The second type has continued to improve over the years (Anbar 1998).

The use of infrared as a diagnostic tool was limited in the past due to the large size of the camera. In addition, the low resolution of the images and the limited power of the computers made thermal images an unattractive tool for diagnosis.

The early 1980s marked the beginning of the use of infrared imaging as a tool in medicine (Frize et al. 2002). Today, with improvements in the imaging systems, the resolution and the quality of the images have dramatically improved (Ring 2004). In addition, fast computers, and small portable infrared cameras renewed interest in using infrared as a diagnostic tool. Figure 2.7 shows (a) first generation infrared camera system, and (b) a modern infrared camera. The first generation system requires cooling with liquid nitrogen, while the modern infrared camera is portable and does not require any cooling agent.

(a)



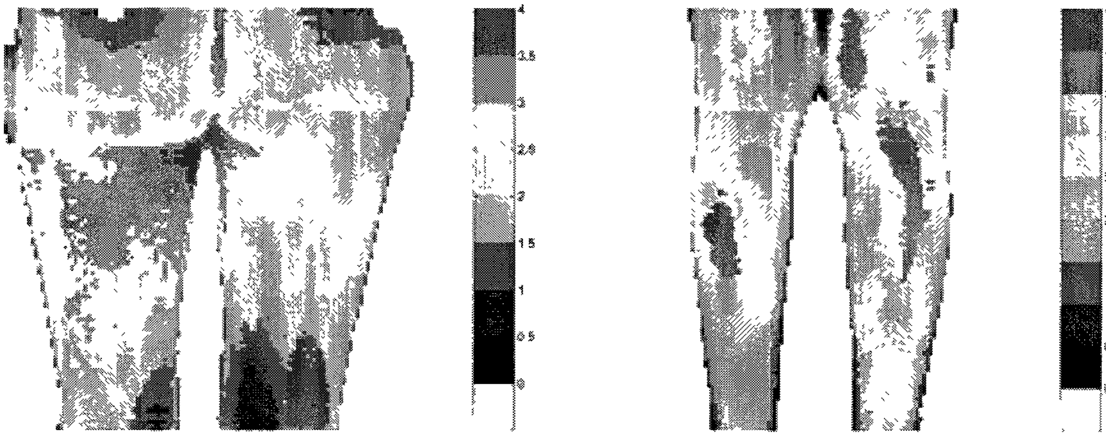
(b)

Figure 2.7: Infrared cameras (a) First generation infrared camera system (b) FLIR ThermoVision 320M. Source for 7(b): http://www.goinfrared.com/canada_fr/cameras/all_cameras.asp#1005

2.9 Thermal Imaging as a Diagnosis Tool

The human skin plays a significant role in regulating the body's temperature. The human skin temperature is related to the body's internal temperature because the skin's temperature is affected by the heat dissipated from vessels and organs within the body (Ring 2004). The human skin's temperature is not uniform over the body; some areas might be warmer due to heat dissipation and other areas might be colder to preserve heat. The flow of blood in the vessels under the skin is regulated by the heartbeat and by the local arteries. The local arteries respond to the autonomous nervous system and can contract or expand depending on the nervous stimuli (Anbar 1991). Since the autonomic nervous system that is responsible for controlling the body thermoregulation is symmetrical, the distribution of the skin temperature of a healthy human body should exhibit a contralateral symmetry (Bryan 1998, Uematsu 1985, Uematsu 1988). An asymmetrical temperature distribution of the human body might be an indication of abnormalities, although the converse is not necessarily true (Herry 2002).

Abnormalities such as inflammation or malignancies can cause an increase in the localized temperature that shows as hot spots in thermal images (Bryan 1998). This principle is shown in Figure 2.8. In figure 2.8 (a) the upper leg has a non uniform heat distribution while (b) has a more uniform heat distribution for both legs. The subject in figure 2.8 (a) is experiencing an abnormality. Abnormalities such as inflammation or malignancies result in increased tissue temperature which would show as a hot area or as an inhomogeneous area in the thermal image. Infrared imaging can be used to detect and study inflammatory diseases because inflammation at the site will result in an asymmetrical distribution of heat at the affected areas (Herry and Frize 2004). In some diseases such as rheumatoid arthritis where the disease affects both sides of the body fairly equally, the temperature asymmetry might not be helpful. In this case the clinicians must find other ways to identify abnormalities; by comparing normal subjects to abnormal subjects to see if there is a significant difference between them (Adea 2009, Hooshmand 2001). The main idea for this thesis is to compare temperature distribution for normal subjects and those suspected of abnormalities due to pain related to piano-playing.



(a) (b)

Figure 2.8: Medical thermal images of the legs (a) Abnormal upper leg, (b) Normal upper leg. Source: Herry and Frize 2004.

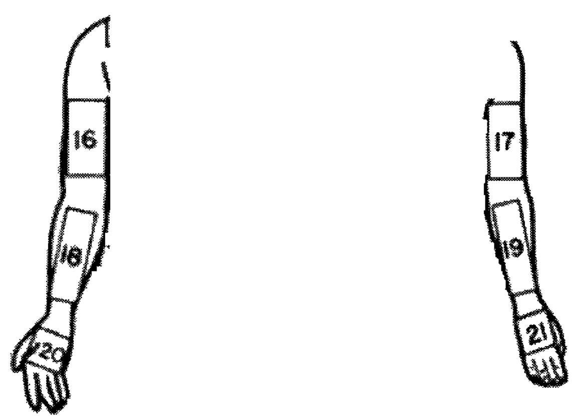
Evaluating thermal images by means of visual assessment of pseudo-coloured or grey images is subjective to the interpretation of the human eye. This means of achieving a diagnosis based on the distribution of the temperature over different areas of the body has been criticized because of the psychological effects of hot and cold colors (Adea 2009, Anbar 1991, Herry 2002, Ng 2009).

In an attempt to quantify thermal images and increase the objectivity of the diagnosis, many researchers tried to identify the normal limits of the temperature of the human body. One approach is to look for the symmetry of the temperature distribution (Aubry-Frize 1981, Frize et al. 2002, Hassan et al. 2003, Kim 1995). Uematsu et al. (1988) conducted a study on 90 healthy volunteers, 38 men and 52 women with age range from 19-59 years old, in an attempt to quantify thermal images of the human body. They divided the human body into regions of interest and calculated the temperature for each region on one side of the body and its opposite region on the other side. Then they calculated the temperature difference (ΔT) between each region and the corresponding region in the form of mean temperature plus or minus a standard deviation; figure

2.9 shows the segmentation of the upper extremity. The authors concluded that the degree of thermal asymmetry of a healthy human body should be small. They formed a table of the average temperature difference for each region. Table 2.1 shows the temperature difference for the upper extremity (Uematsu et al. 1988).

The body region	mean + or – standard deviation
Hand palmar	0.24° + or - 0.23° Celsius
Hand dorsal	0.31° + or – 0.25° Celsius
Arm anterior	0.25° + or – 0.21° Celsius
Arm posterior	0.31° + or – 0.22° Celsius

Table 2.1: The temperature difference between the left and the right side of the upper extremity. Source: Uematsu et al. 1988.



(a) (b)

Figure 2.9: The upper extremity segmentation (a) anterior view (b) dorsal view. Source: Uematsu et al.1988.

In order to achieve good results with thermography, a restricted protocol must be followed. The room temperature has to be controlled, and the patients must stay away from any activities that might alter their skin temperature such as tanning, physical exercise, or drinking alcohol or caffeine (Ring 1995, Ring and Ammer 2000). We will explain the imaging protocol in detail in the methodology chapter.

2.10 Applications of Medical Infrared Imaging

Medical infrared imaging is a non-invasive passive technique that has been widely used to study pain (Frize 2003, Herry 2002), arthritis (Collins and Cosh 1970, Ring 1995, Ring 1998, Frize et al. 2009, Adea 2009), and breast cancer (Frize et al. 2002, Head et al. 1997, Koay 2004, Ng 2009, Ohashi and Uchida 2000). Frize et al. (2002) used temperature symmetry to detect breast cancer in thermal images by applying three methods. First, they calculated the mean temperature of the right and left breast. The results were considered abnormal if the difference was higher than 0.5 degrees Celsius. The second method involved dividing each breast into four quadrants and calculating the mean difference between the temperature of each quadrant and the temperature of the opposite quadrant in the second breast. If the mean difference was between 0.5 degree Celsius and 1 degree Celsius, then a score of 0.5 was assigned. If the mean temperature difference was higher than 1 degree Celsius, then a score of 1 was assigned. The final score is a simple addition of all the quadrants scores and has a value between 0 and 4. An index of 1 or higher was considered abnormal. The third method was done by calculating the total mean temperature for each breast by a simple addition of the mean temperature for all four quadrants in each breast. If the absolute temperature mean difference calculated between the left and right breast is greater than one degree Celsius then the results were considered abnormal. The same approach was used previously by Head et al. in 1997 to quantify temperature measurements for the breast. Frize et al. compared their results to Head et al.'s (1997) and found the third method was successful in differentiating between normal and abnormal subjects if the threshold was raised to 1.5 degrees Celsius.

Collins and Cosh (1970) used infrared imaging to study arthritis diseases. In 1974 Collins et al. developed a thermographic index (TI) to quantify the results.

$$TI = \Sigma (\Delta t\ a)/A \tag{2.9}$$

Where:

Δt: the difference between the measured isothermal temperature and the lowest recorded isothermal

a: the area occupied by the isotherm,

A: the total area of the thermogram (cm)

Σ: The summation taken over the different areas in the image being quantified.

Collins et al. (1974) found that the thermographic index decreased with the treatment. In 1979 Bird et al. used thermography to monitor the effect of three different drugs on 30 patients who suffered from rheumatoid arthritis. They divided the patients into three groups and injected the knees of each group with a different drug. They demonstrated that thermography can be used to assess which drug gave the best results. In 1983 Salisbury et al. compared thermal patterns for normal ankle, knee, and elbow joints to those with synovitis diseases. They showed that those with synovitis diseases show abnormal thermal patterns compared to the normal ones. Salisbury et al. (1983) proposed that the quantification of synovitis by thermography should be identified by abnormal thermal patterns rather than using an absolute skin temperature. In 1994 Ring used thermal imaging to assess drug treatments for arthritis and found that thermal imaging, if conducted under restrict imaging protocol, is an inexpensive and reliable tool to monitor the effect of drug treatments on patients with arthritis.

Usually the process of selecting the area to be analyzed is done manually. The challenge in doing so is the difficulty of distinguishing different levels of color within the thermal image. There is ongoing research to automate the process of selecting the region of interest within the infrared thermal images. For example, Scales et al. (2004) proposed a method to segment the breast area based on the breast shape. Another attempt was made by Herry et al. (2007 and 2008) to automate the process of finding temperature abnormalities within infrared images.

2.11 Quantification of Pain Measurements using Infrared Imaging

Pain is the most pronounced symptom in people who suffer from musculoskeletal disorders and rheumatic diseases. The International Association for the Study of Pain describes pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage." (Sokka 2003).

Pain is a subjective term that depends on the person's assessment rather than the assessment of data obtained from the lab or a medical test. There have been efforts to assess pain through objective terms but so far it has not been achieved. Pain questionnaires obtained from people with pain have been used to monitor a person's condition over time, to assess if the pain increases or decreases; however, the questionnaires remain more of a research tool than a diagnostic tool (Sokka 2003).

The pain visual analogue scale was used in psychology in the early 1900 and was used in rheumatology by Huskisson et al. in the late 1970s. The standard visual analogue scale is from zero to ten. At zero, the patient records no pain and at 10, the pain is as bad as it can be (Sokka 2003).

Infrared thermal imaging has been used as an assessment tool to study pain (LeRoy et al. 1985, Herry 2002, Herry 2004). LeRoy et al. (1985) used clinical thermography to detect lower back pain and showed that it can be helpful in monitoring the treatment of chronic pain and postoperative management of patients suffering from low back pain syndromes. Herry (2002) used infrared images of different body regions to assess pain. First, he removed the noise from the infrared images. Next, he used a threshold approach to isolate the background or the unwanted information from the image. Then, he divided each region into smaller regions and calculated temperature symmetry. He compared different methods to predict pain and found that infrared can be used to detect pain if the right approach is applied. A similar study that used temperature asymmetry to detect pain was carried out by Frize et al. (2003)

In 2005 Herry et al. used infrared imaging in studying musculoskeletal disorders as a result of piano-playing. They plotted temperature versus time for the muscles of the arm for each participant. The results showed that there are temperature variations due to muscle work during piano-playing, and these variations are not consistent among pianists. This thesis is a continuation of earlier work exploring the use of infrared imaging as a tool to assess pain as a result of musculoskeletal disorders in piano players..

Chapter 3

Methodology

This chapter explains in detail the methodology used in this research to collect infrared images and to analyse them. First, ethics approval for the project was obtained. Second, information letters were distributed to the potential subjects highlighting the research goal and the imaging protocol. If subjects agreed to participate, they had to sign consent forms and complete a questionnaire. Finally, the subjects were instructed to play the piano according to a certain protocol. Infrared images were taken before, during, and after piano-playing.

This chapter also explains the imaging procedure and protocols that were followed for collecting the infrared images. A description of the infrared camera that was used in the research and a brief explanation of the Researcher software that was used to collect the images are given.

3.1 Ethics Approval

Ethics approval is essential for all research that involves human subjects or animals. It ensures the following: the project is harmless and looks after the participants interests; the data is collected and used by the researchers for the purpose of the research as defined in the applications; the data is collected and saved in a confidential manner, not identifying the subjects. There were two main stages of this project. The first stage was an exploratory stage to see if different piano players have different patterns of upper arms muscle temperature variation over time during piano-playing. The second stage was done to see if pianists without pain related to piano-playing is statistically different from pianists with pain related to piano-playing. Since the images were collected in two different stages by two different researchers, two ethics approvals were obtained. The first ethics approval was obtained in 2006 by C. Herry and the second one was obtained in 2010 by S. Mohamed. Since the image collection took place at the music studio of the research laboratory in piano pedagogy led by Professor Gilles Comeau in the department of music at the University of Ottawa, the research proposal was approved by the University of Ottawa's ethics committee both times.

3.2 Participant Recruitment

The first stage of image collection recruited piano players of different ages, including those who were younger than eighteen years old. The second stage of image collection focused on recruiting subjects, who were older than eighteen years old; their experience level of playing the piano ranged from professional players such as music teachers and students, to regular piano players who played the piano a few hours a week and were all above intermediate level.

Information letters stating the goal of the research and highlighting the imaging protocol and procedure were sent to participants who were interested in participating in the research. The letters also contained a detailed description of the experiment, and the location of the experiment. If the person agreed to participate, then he or she had to sign a consent form and to fill-out a questionnaire. The consent form ensured that each subject had agreed to participate. The questionnaire asked questions that are essential for the research, such as age, gender of the participant, current occupation, and number of years completed at the conservatory. It also contained questions regarding the number of hours the person plays the piano per week, and how long the person had been playing the piano. If the person had any pain related to piano-playing, he or she had to answer a series of questions regarding the pain location and duration. A copy of the information letters, consent forms, and questionnaires for the two stages of image collection are attached in appendix A.

3.3 Infrared Cameras

The infrared camera that was used in the first stage of image collection is FLIR ThermoVision A40M. The camera uses an uncooled microbolometer focal plane array. It measures 17 cm in length, 7 cm in width, 7 cm in height, and weights 0.7 kg. The camera has an autofocus setting and pixel resolution of 320 × 240. The camera captures the thermal images with a refresh rate of 50 or 60 Hz. The camera can measure temperature in two settings: from -20° to 120° Celsius and from 0° to 350° Celsius. The camera has a thermal sensitivity of 0.08° Celsius up to 30° Celsius temperature. For the purpose of our research, we set the camera to measure temperature between -20° Celsius to 120° Celsius. The camera was connected to the laptop via PC card. Figure 3.1 shows both cameras that were used in the research.

The second set of images were taken by FLIR 320M. The camera uses an uncooled microbolometer focal plane array. It measures 20.7cm in length, 9.2cm in width, 10.9 cm in heights, and weighs approximately 1.5 kg. The camera has two settings for measuring temperature: from -40° to 120° Celsius, and from 0° to 500 Celsius. It can detect temperature differences within 0.08° Celsius at 30° C. The camera has a resolution of 320×240 and it is capable of acquiring images at 60 Hz refresh rate.

The camera was connected directly to a laptop for real time image display and recording. Special software comes with the camera that can be used for recording sequences of images of still or moving objects. Later the image sequence can be divided into frames for image analysis.

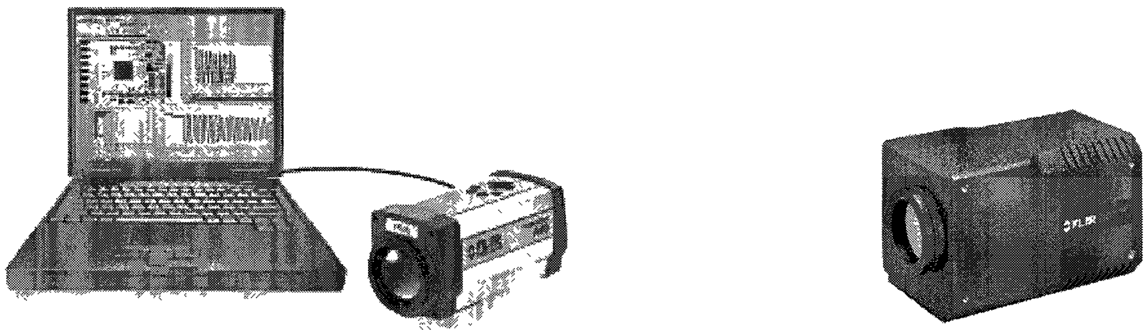


Figure 3.1: Modern infrared cameras A40 M (left) & 320 M (right). Both cameras were connected to a laptop where sequence of images can be recorded. Source: www.flir.ca

3.4 Preparation

Participants were advised to wear sleeveless shirts to expose the hands, arms, and shoulders to the infrared camera. Since infrared thermography records the skin temperature, which can be affected by several factors, the participants were asked to follow certain preparation guidelines.

- No talcum powder, lotion, drug or deodorant should be used on the skin on the day of the session.
- No alcoholic beverages should be consumed 24 hours prior to the imaging session.
- No hot beverages should be consumed for at least 1 hour prior to the session.

- Avoid the use of procedures such as electromyography, acupuncture, myelography, transcutaneous electrical stimulation, hot or cold patches, or any other form of physiotherapy for at least 24 hours prior to the session.
- Avoid prolonged sun exposure for at least one week prior to the session.
- No smoking for at least 2 hours prior to the session.
- Avoid wearing rings, bracelets, or watches during the session.
- Avoid intense physical exercises for at least 4 hours prior to the session.

3.5 Images Collection Protocol

The first set of images was taken for eleven participants in 2006 by C. Herry. The second set of images was collected in 2010 by S. Mohamed and included 9 pianists. The images were taken before, during and after playing the piano.

The room temperature and humidity settings for the images collected in 2010 were controlled through the entire imaging session. Figure 3.2 shows the piano lab at University of Ottawa, where the images were taken. The room temperature was kept at 19.9° Celsius.

The subjects in the first stage of the image collection were allowed to choose which musical exercises to play since the first stage focused on detecting different heat patterns for the upper arm muscles. However, they were imaged after their piano practice every ten minutes for an hour or until there was no further change in the temperature of their hands, arms, or shoulders.

For the second set of images, the subjects were instructed to play specific piano exercises. The first set of piano exercises was easy, the second set of exercises was of a medium difficulty, and the last set of exercises was physically demanding. We wanted to observe the change in the arms' and hands' temperature as the exercises get harder and playing the piano becomes more physically demanding. All participants prior to the start of the imaging session were asked to sit for fifteen minutes to give the skin the chance to stabilize to the room temperature. The first set of images was taken after the fifteen minutes of body temperature stabilization and then the participants were instructed to play the piano as follows:

- First, to play the piano for 10 minutes. The level of performance includes sight reading exercises at the grade 4 level; a second set of infrared images was taken immediately after finishing the 10 minute performance.
- Next, to play scales in sixteenth notes, four octaves at 112 beats per minute for 10 minutes, as follows:
  - Play all major scales (C, C#, D, E^b, etc.), going up by half a tone.
  - Play all minor scales (C, C#, D, E^b, E, etc.), harmonic and melodic, going up by half a tone.

  A third set of infrared images was taken immediately after the participants stopped playing.
  - Finally, to play octave scales for five minutes or less if they became very tired, following this pattern: Play all major scales (C, C#, D, E^b, etc.) going up by half a tone. A fourth set of infrared images was taken immediately after they stopped playing.

All participants were instructed to stop playing the piano at any time if they felt tired or experienced pain. Two more sets of images were taken, one after fifteen minutes and one after half an hour after playing the last set of piano exercises.

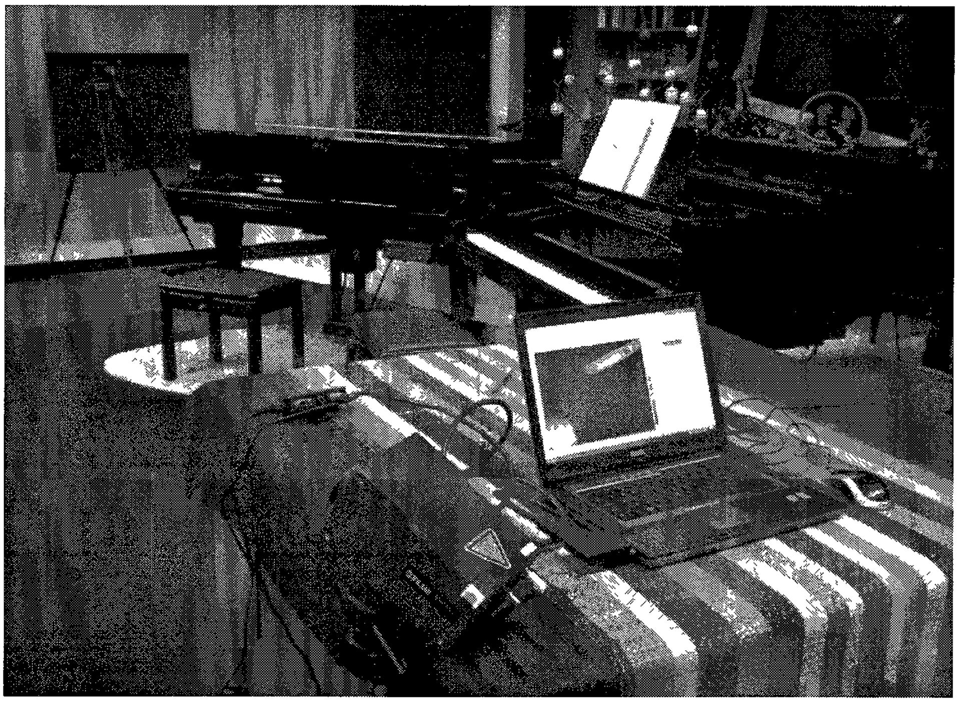
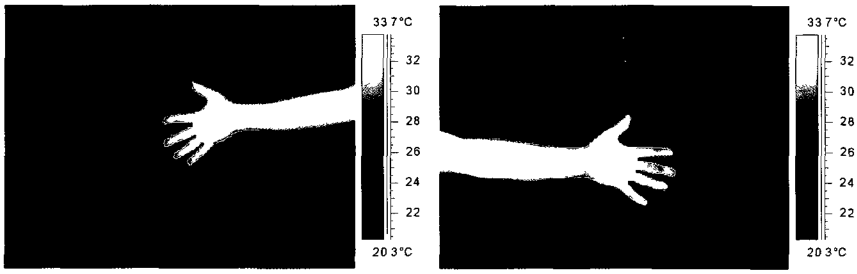


Figure 3.2: The piano lab at the University of Ottawa.

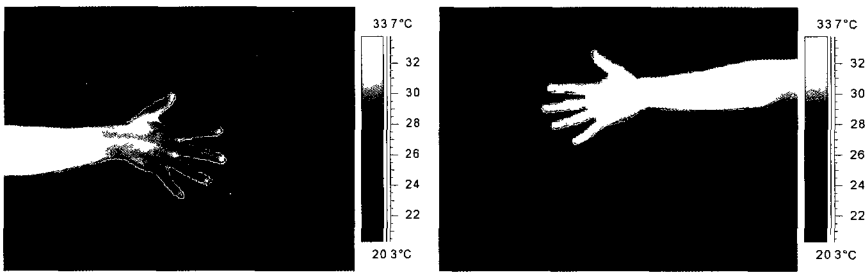
3.6 Image Collection

Both infrared cameras that were used for stages one and two were connected to a laptop that has software called Researcher. The Researcher software was obtained from FLIR systems and was used to collect the infrared thermal images. The software allows the user to see real time infrared images, record a sequence of images, and store the sequence. The sequence can then be played back and divided into frames that can be read by Matlab for analysis. The software also allows the user to make adjustments to an emissivity table, for our purpose of imaging the skin we set emissivity at 0.9. The subjects were imaged at a distance of one meter to two meters and were asked to stand up while being imaged. Images of the hands dorsal (back) and palmar (front), and arms interior and posterior, were collected during the imaging sessions as shown in figures 3.3, 3.4, 3.5 and 3.6.



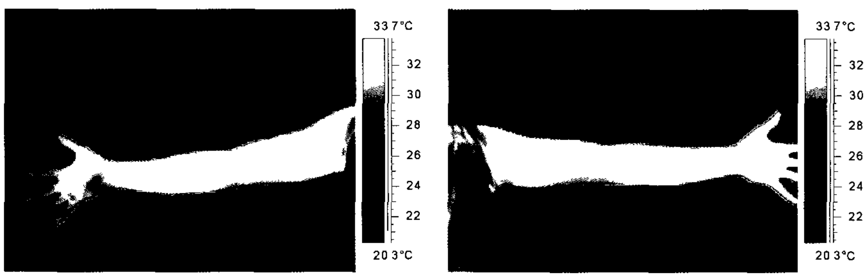
(a) (b)

Figure 3.3: Thermal images of the hands: (a) right hand palmar, (b) left hand palmar.



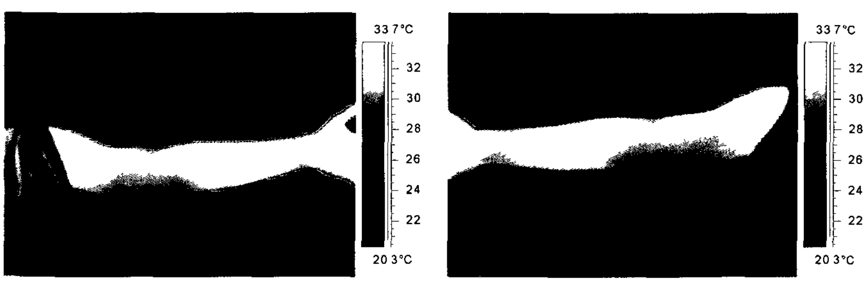
(a) (b)

Figure 3.4: Thermal images of the hands: (a) right hand dorsal, (b) left hand dorsal.



(a) (b)

Figure 3.5: Thermal image of the anterior of the arms: (a) right arm anterior, (b) left arm anterior.



(a) (b)

Figure 3.6: Thermal images of the exterior of arms: (a) right arm dorsal, (b)left arm dorsal.

3.7 Background Subtraction

All the image sequences were converted to a series of Mat files using the Researcher software. A Mat file is one of the file formats supported by Matlab. Each Mat file can then be read into Matlab and the mean temperature can be claculated for each sequence at a specific time. The Matlab code used for analysis is given in Appendix B. Our first step in analyzing the images involved isolating the background. We initially chose our threshold to be 23° Celsius. However, we found that a value below or equal to 23° Celsius introduced noise and unwanted details in our image, so we proceeded to increment the threshold by 0.1° Celsius until we obtained a clear segmentation. We found that the value of 24° Celsius (297 Kelvin) was successful in isolating the hand and arm regions from the background for most of the images. For a few of the images, we got better results with a threshold of 23.8°Celsius. A value of one was given to pixels greater than or equal to the threshold value, otherwise a value of zero was assigned to the pixel. Figure 3.7 shows the images after isolating the background.

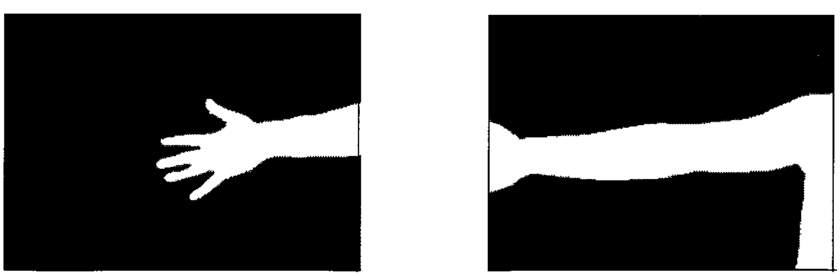


Figure 3.7: The images after isolating the background.

3.8 Selection of the Regions of Interest

Since we were interested in the temperature variation of the hands and arms area, we focused on dividing and selecting specific areas to obeserve the temperature change. The regions of interest were the same for the control group, which did not suffer from pain related to piano-playing, and the group that have pain related to piano-playing. The segmentation was done for both the front (anterior) and back (posterior) view of the hands and arms. For the hands we chose to focus on the palms because the fingers of the hands for some players were getting colder than the room temperature during piano-playing. The selection of the region of interest was done manually using a function in Matlab called roiopoly, which allows the user to draw a polygon around the region of interest. The selection of the regions of interest on the original image are shown in figure 3.8. The resulting images after isolating the background and applying the threshold are shown in figure 3.9.

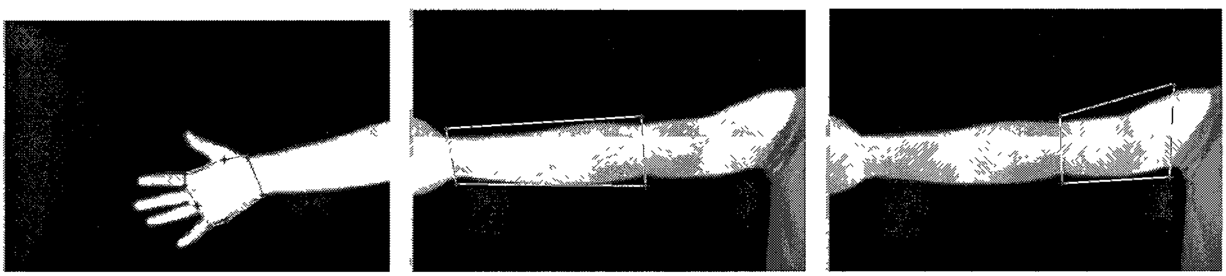


Figure 3.8: Selecting the region of interest for the hands and arms.

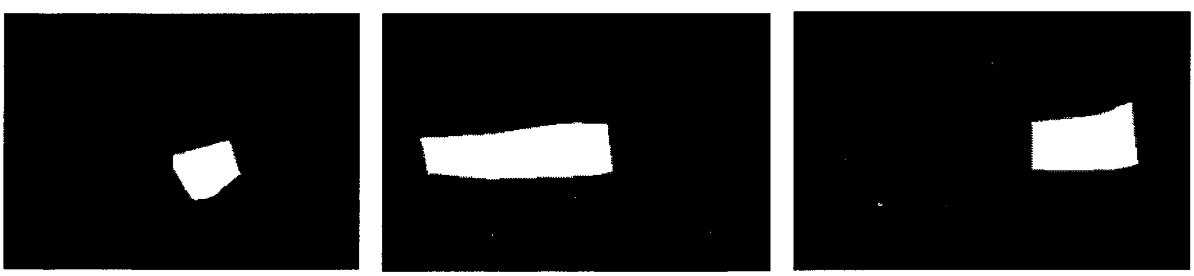


Figure 3.9: The region of interests for the hand and arm after isolating the background and applying the threshold value.

3.9 Statistical Analysis in the Regions of Interest

For each image sequence, the mean temperature in the region of interest was calculated; the mean temperature is the summation of the temperature values of all the pixels in the region of interest divided by the number of pixels. Our first approach was to see if pianists with pain and pianists without pain related to piano-playing are statistically different at any point in time, before, during, or after playing the piano. The second approach was to record the difference of temperature variation over time in the hand and arm during the imaging session.

First we tested our data for normality by applying Lilliefors test to our data. Lilliefors test is a two sided goodness-of-fit test that is used to determine if the data came from a normal distribution or not. Lilliefors test is implemented in Matlab under the function name Lillietest. The Lillietest function takes data in vector x and it returns H=0 if it accepts the null hypothesis that the data is normally distributed or H=1 if the data is not normally distributed, i.e. it rejects the null hypothesis. The Lilliefors test statistic is the same as the Kolmogorov-Smirnov (KS) test and is calculated as follows:

$$KS = \max_x |SCDF(x) - CDF(x)| \qquad (3.1)$$

Where:

SCDF: the cumulative distribution function estimated from the data sample.

CDF: the normal cumulative distribution function with the same mean and standard deviation as the data sample.

The Lilliefors test uses a table of critical values for data that has a sample size less than 1000 and performs the test at significance levels, known as alpha, between 0.001 and 0.50. It returns the KS values, the H value, and the P value, which is computed using the inverse interpolation into the critical values table. If the P value is small, then there is some doubt about the null hypothesis. If the critical value is bigger than the KS value, then the null hypothesis is rejected at the specified significance level alpha. Depending on the H value, we would proceed by using the ANOVA test if the data is normal. Otherwise, we would use the Kurskal-Wallis test and the Ranksum test.

3.10 Histogram

The histogram of a grey level image is a graphical representation of the frequency of occurrence of each grey level. The histogram is considered one of the main tools to understand and analyze an image (Bovik 2009). We expected pianists with pain would have higher temperature values than those without pain. Also we expected them to have a narrower temperature range than those who do not have pain related to piano-playing.

The histogram function “hist” in Matlab takes the region of interest temperature values as an input and distributes them along the x-axis between the minimum and maximum values. We used the “hist” function to produce a graph that shows the frequency of occurrence of each temperature in the region of interest. In the next chapter, we will explain in detail how we used each function and discuss the analysis results.

Chapter 4

Results and Discussion

In this chapter we discuss the analysis of our data, and our findings. Since our goal is to find statistical differences between the pianists without pain and the pianists with pain related to piano-playing, we tried different approaches to show that two groups can be distinguished from each other. We explain each approach in detail below.

We applied our methods to the hands, the lower arms, and the upper arms to see which parts of the upper extremity get affected the most by pain related to piano-playing and can give us more information to classify the subjects into one of two groups (pianists with pain or pianist without pain).

4.1 Data Collection

We had 9 participants in 2010, with ages ranging from 20 to 65 years old, included music teachers, music students, and non-music students, who are all above intermediate level and who played the piano regularly. Three of the participants did not have any pain related piano-playing nor did they have any musculoskeletal disorder that affected their muscles or joints. Out of the six participants with pain, three suffered from pain during the imaging session, and two did not have pain during the imaging session. Out of the two participants who did have pain at the time of the imaging session, one suffered from stiffness related to piano-playing as well as a musculoskeletal disorder, and the second participant indicated that the pain starts after playing the piano for a long time. It was not clear whether we should classify the last participant as a pianist with or without pain. We chose to classify the participant as a pianist with pain.

The data collected in 2006 by C. Herry contained 11 participants; their ages ranged from 8 to 40 years old. We excluded the participants who were younger than 13 years old. The remaining 9 participants had one person who suffered from pain related to piano-playing and one person who suffered from sweaty hands.

To differentiate between the new participants who were imaged in 2010 from the participants who were imaged in 2006, we refer to the 2010 participants as P12, P13, P14,...,P20, while P1-P9 represent the 2006 participants.

The questionnaire informed us on which pianists have pain related to piano-playing and which pianists do not. Also, it informed us on who does warm-ups who does not. Participants P12, P13, P14, P15, P16, and P17 indicated that they practice musical warm-ups regularly while participants P18, P19, and P20 indicated that they do not. We did not allow the participants to practice their usual warm-ups; however the first piano exercise was an easy exercise that they chose from an easy sight reading grade 4 book. Table 4.1 summarizes the information we gathered from our 2010 participants, and table 4.2 summarizes the information that was gathered in 2006 by C. Herry.

	Pain/no pain	Pain location	Right / left handed	Occupation	Musical Warm-ups
P12	Pain	In the back between the shoulder blades.	R	Music student	Yes
P13	Pain (couldn't finish the experiment)	Pain in the neck that radiates down to the fingers from vertebrae c4 to c5. As a result of disc movement pain shifts from the left to the right hand and vice versa. The pain was on the left side at the time of the imaging session.	R	Music teacher	Yes
P14	No pain	N/A	R	Student (other discipline)	Yes
P15	Pain during the experiment	Tendonitis, pain in both arms.	R	Music student	Yes
P16	No pain	N/A	R	Student (other discipline)	Yes
P17	No pain	N/A	R	Music teacher	Yes
P18	Pain depending on the piano-playing duration	Cramps in both hands and weakness in arms after playing for a long time. Did not have pain during the imaging session.	R	Music student	No
P19	Pain	Joints, forearms, shoulders and sides of torso.	R	Music teacher	No
P20	Stiffness	Stiffness in left index finger/ suffers from musculoskeletal disorder.	L	Student (other discipline)	No

Table 4.1: Participants P12 - P20, who were imaged in 2010 by S. Mohamed.

	Pain/no pain	Pain location	Musical Warm-up
P1	No pain. Sweaty hands	N/A	Yes
P2	No pain	N/A	Yes
P3	No pain	N/A	Yes
P4	No pain	N/A	N/A
P5	No pain	N/A	N/A
P6	Pain	Suffers from musculoskeletal disorder.	Yes
P7	No pain	N/A	Yes
P8	No pain	N/A	Yes
P9	No pain	N/A	No

Table 4.2: Participants P1- P9, who were tested in 2006 by C. Herry.

4.2 Testing the Data for Normality

We used the Lilliefors test that we described in the previous chapter to examine whether our data had a normal distribution or not. Lilliefors test is implemented in Matlab under the name lillietest. When we initially tested our data using the command lillietest (X), where X is a vector that contains the data to be tested for normality, we received a warning that P is larger than the largest tabulated value and that we should use the Monte-Carlo form of the lillietest. Our function took the following form:

[H,P,KSTAT,CRITVAL] = LILLIETEST(X,ALPHA,DISTR,MCTOL). The vector X contained the mean temperature values at time 0 (before participants started playing the piano) for each 12 measurements (right hand palmar, right hand dorsal, right arm anterior for the lower part of the arm, right arm dorsal for the lower part of the arm, right arm anterior for the upper part of the arm, right arm dorsal for the lower part of the arm, and similar region of interests for the left arm). Alpha is the significance level that takes a value between 0.001 and 0.5. We chose alpha to be 0.05, which represents a 95 percent confidence level. The function also takes a distribution type that can be normal or exponential. We chose the distribution type to be normal. MCTOL is Monte-Carlo approximation for the P value. We chose MCTOL value to be one. After running the test, we received H=0, P=0.7260, KSTAT=0.0744, and CRITVAL=0.1285.

According to the lillietest function, if KSTAT is < CRITVAL, then we cannot reject the null hypothesis. In our case, since the data is normally distributed, we proceeded with the ANOVA test. Our goal was to see if there was a statistical difference between the measurement of temperature of pianists without pain, and of pianists with pain related to piano-playing. The Matlab file for lillietest is provided in index B.

4.3 ANOVA Test

The ANOVA test compares the mean of two or more groups to see if they have equal means. The ANOVA test can be implemented in various programming languages such as C, but we chose to use the existing function in Matlab. The ANOVA test is implemented in Matlab under the function name ANOVA1. The function takes a matrix X as an input, where each column represents an independent sample that contains mutually independent observations. For the purpose of our research, the matrix X has two columns: one column contained the mean temperature measurements for each part of the hand/arm at a specific time for pianists without pain related to piano-playing and the second column contained the data for pianists with pain. The function returns a value called the p value; if the p value is close to zero, then there is a doubt on the hypothesis and at least one sample mean is different from the other sample mean. Also, the function returns a box plot for each column in the matrix X. Each box represents the data points for the specific group, the middle line in each box represents the median, the edges of the box are the 25th and 75th percentiles, and the whiskers extend to the most extreme data points not including the outliers, which are plotted individually as "+" sign. An outlier is a value that is more than 1.5 times the interquartile range far from the top or the bottom of the box, but can be adjusted if additional arguments are provided. Whiskers are drawn from the end of the interquartile ranges to the furthest observation within the length of the whiskers. A non-centred median line indicates a skewed sample. The notches at the end of each box are used to compare the medians by calculating the width of the notch to see if they overlap or not. A non-overlapping notch means that the two boxes have different medians at the 5% significance level. If the sample size is small as it is in this case, the notches may get extended beyond the end of the box. The following sections summarize the ANOVA test results.

ANOVA test at time t=0

We ran the ANOVA test for the mean temperature measurements for the hands (right hand dorsal, right hand palmar, left hand dorsal, left hand palmar) at time t=0 before participants started playing the piano, with the expectation that there would not be a statistical difference between pianists without pain and pianists with pain related to piano playing. Since participant P18 did not suffer from pain during piano-playing, we were not sure if he/she should be classified as pianist without pain related to piano-playing or as a pianist with pain. We decided to classify P18 as pianist with pain related to piano-playing. The ANOVA test returned $p=7.9\times10^{-6}$ indicating that the two groups are statistically different, which is contradictory to what we expected. The box plot for the ANOVA test results is shown in figure 4.1.

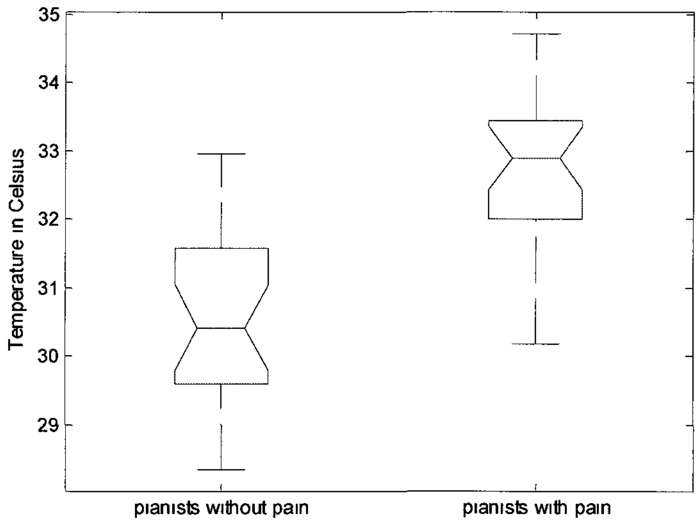


Figure 4.1: ANOVA test box plot for the hand temperatures, at time t=0, for images collected in 2010.

Then, we ran the test on the data collected in 2006 and the data collected in 2010 combined to see if the participants are statistically different at time t=0 based on the hand temperatures. We tested the data groups twice, once with P18 classified as participant without pain and a second time with P18 classified as a participant with pain related to piano-playing. The test returned $p=1.3\times10^{-8}$ in the first case and $p=4.1\times10^{-8}$ in the second case. Both results showed that the two groups are statistically different even before they started playing the piano. Again that was contradictory to our initial expectation that there would not be a difference between the two groups. However, the box plot in the first case did not have outliers as shown in figure 4.2 while the box plot in the second case had Participant P18 as outlier as shown in figure 4.3.

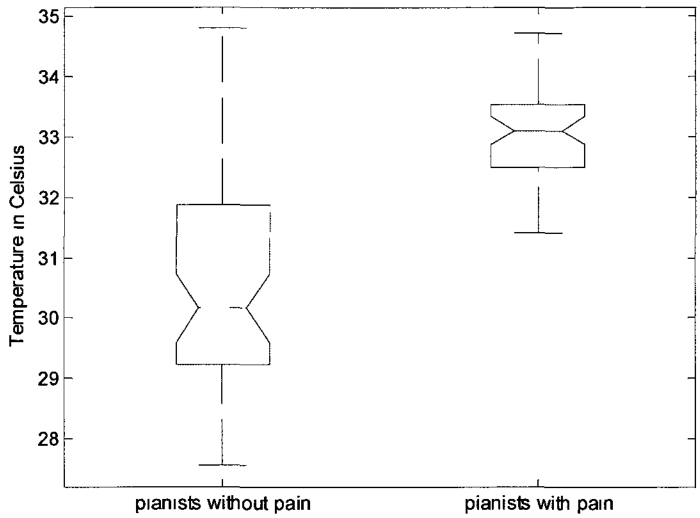


Figure 4.2: ANOVA test box plot for the hand temperatures, at time t=0, for both sets of images taken in 2006 and 2010. Participant P18 is classified as pianist without pain.

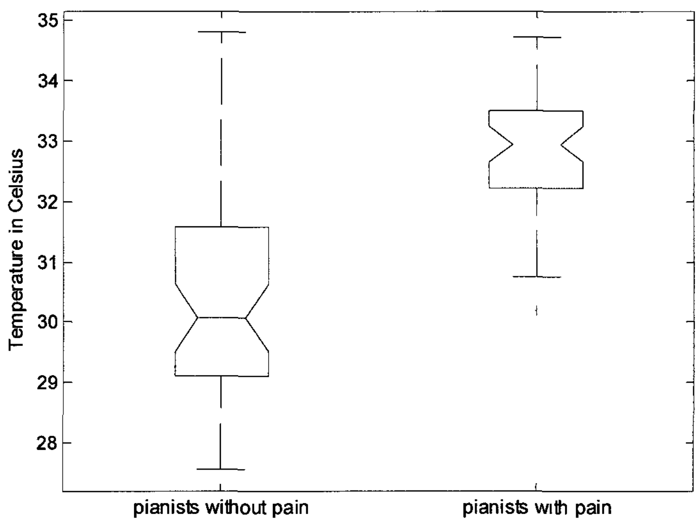


Figure 4.3: ANOVA test box plot for the hand temperatures, at time t=0, for both sets of images taken in 2006 and 2010. Participant P18 is classified as pianist with pain and is shows as an outlier "+".

Next, we ran the same test for the mean temperature measurements for the lower arms at $t=0$ to see if the two groups are different. The test returned $p=0.88$, which shows that the test could not establish that the two groups were different as shown in figure 4.4. Then we ran the test at time $t=0$, for the upper arm mean temperature measurements. The test returned $p=0.06$, which is very close to but still above the accepted significance threshold of 0.05. The p value indicated that the test could not distinguish between the two groups based on the upper arm temperature measurements as shown in figure 4.5. Finally we ran the ANOVA test on the mean temperature measurements for the lower and upper arms combined and we received $p=0.21$, which still could not differentiate the two groups.

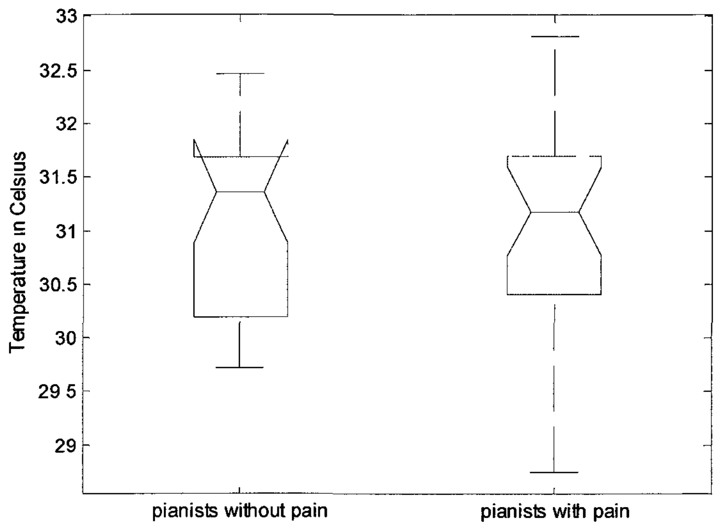


Figure 4.4: ANOVA test box plot for the lower arm temperatures, at time t=0, for images collected in 2010.

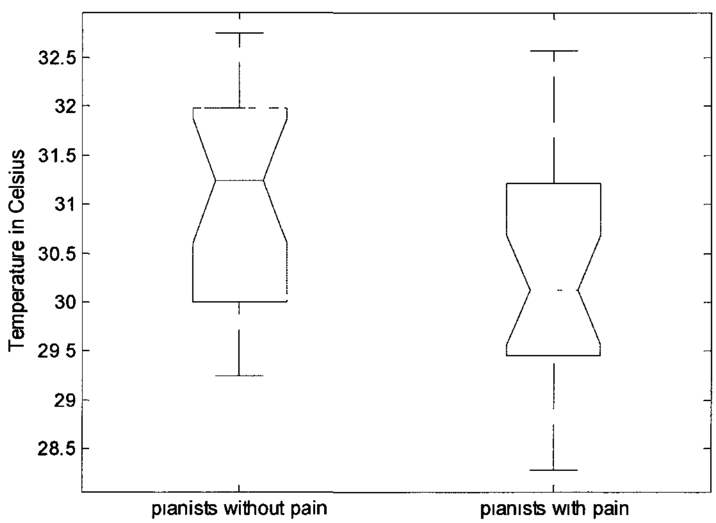


Figure 4.5: ANOVA test box plot for the upper arm temperatures, at time t=0, for images collected in 2010.

ANOVA test at time t=1, after playing the first piano exercise

We ran the ANOVA test for the mean temperature measurements for the hands at time t=1 after the subjects had just finished playing the first piano exercise. The test returned

$p=5.2\times10^{-7}$. The box plot in figure 4.6 shows that the two groups can be distinguished from each other based on their hand temperatures.

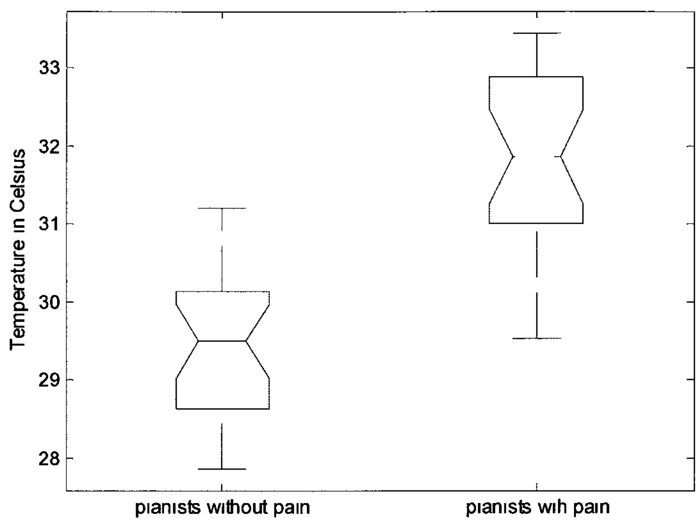


Figure 4.6: ANOVA test box plot for the hand temperatures, at time t=1, for images collected in 2010.

ANOVA test at time t=2 after playing the second set of piano exercises

We ran the ANOVA test for the mean temperature measurements for the hands at time t=1 after the participants had just finished playing the second set of piano exercises. The test returned $p=5.2\times10^{-7}$, indicating that the two groups could be distinguished from each other based on their hand temperatures. The box plot of the temperature values is shown in figure 4.7.

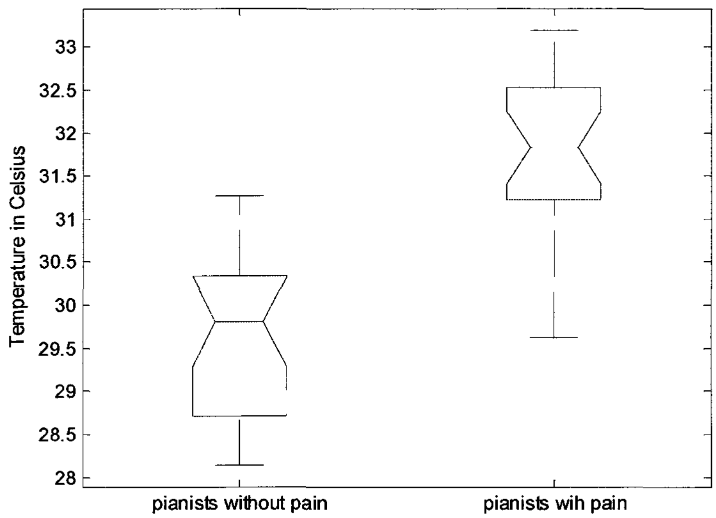


Figure 4.7: ANOVA test box plot for the hand temperatures, at time t=2, for images collected in 2010.

ANOVA test at t=3, after playing the final piano exercise

We ran the ANOVA test for the hands' mean temperature measurements after playing the last set of piano exercises for the data gathered in 2010. The test returned $p=3.5\times10^{-5}$, which is near zero, indicating that the means for the two groups are different as shown in figure 4.8. We would like to point out that the third set of piano exercises were physically demanding, so each subject played for a different amount of time: pianists with pain played only for a few seconds while pianists without pain were able to play longer. This might have resulted in elevating the temperature for the pianists wihout pain.

We also ran the ANOVA test to see if we could differentiate the two groups statistically based on the lower arms' mean temperature measurments for time t=3. The test returned p=0.78, which means that we could not differentiate the two groups statistically based on their lower arm temperature measurements.

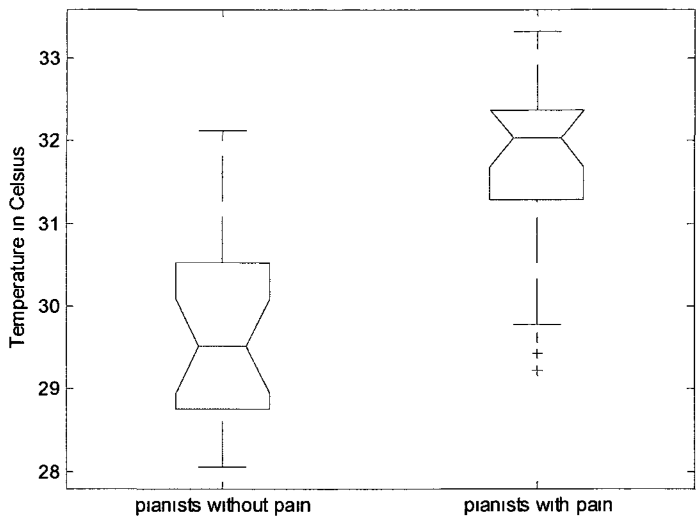


Figure 4.8: ANOVA test box plot for the hand temperatures, at time t=3, the outliers are represented by "+" signs.

ANOVA test at the end of the experiment

Finally, we ran the ANOVA test on the mean temperature measurements of the hands obtained at the end of the imaging session. The test returned $p=6.9\times10^{-5}$, indicating that the two groups are statistically different. The box plot is shown in figure 4.9.

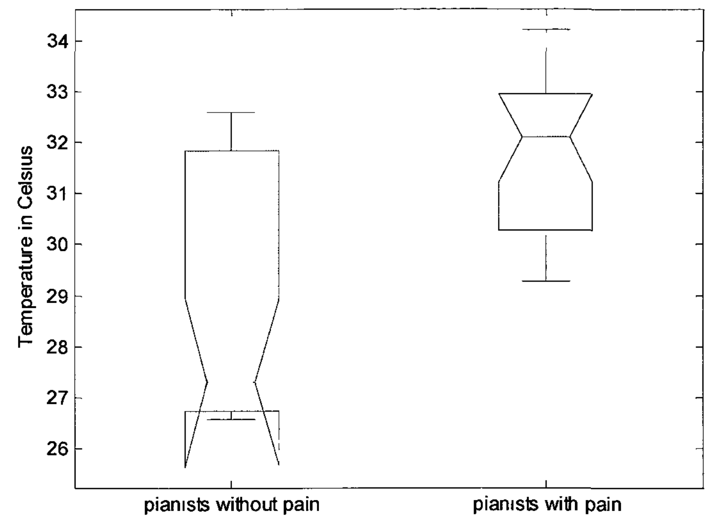


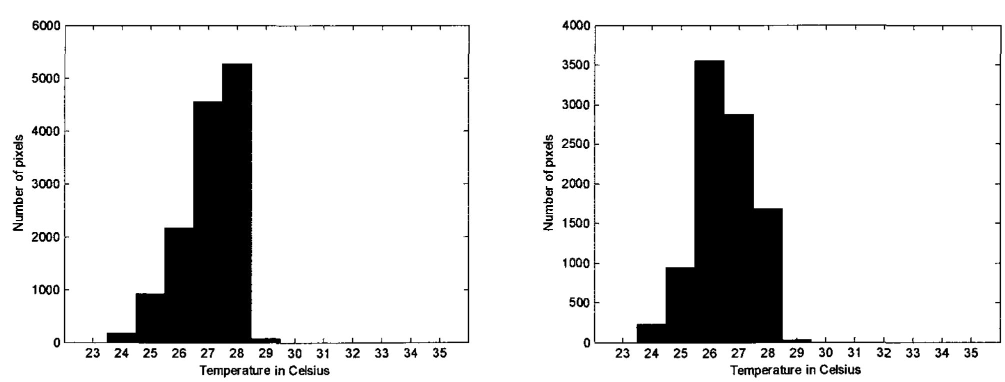
Figure 4.9: ANOVA test box plot for the hand temperatures, at the end of the imaging session. The notches are extended beyond the end of the box due to the small sample size.

From the ANOVA test results, we concluded the following. First, it is possible to distinguish pianists with pain from pianists without pain even before they started playing the piano. This finding indicates that there is permanent damage to the ligaments and tendons in the hand as a result of piano playing. Second, it is difficult to classify the participants as pianist with or without pain if they suffer from pain under certain conditions such as playing for a long time. Third, the difference in the temperature of the hands was statistically significant; the hand temperatures contain useful information that can help in distinguishing between pianists with pain and pianists without pain. Fourth, the lower arm temperature measurements were not successful in identifying pianists with pain from pianists without pain. Finally, we can also speculate that some pianists push themselves really hard and might be at the risk of developing pain related to piano-playing later in life.

4.4 Histogram Visualization

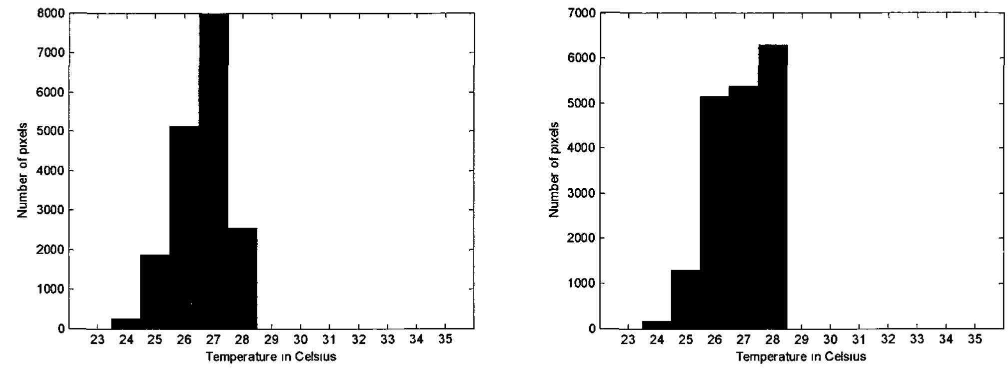
We plotted the histogram for the right hand dorsal and the left hand dorsal for each participant to see if we could visualize the difference between the pianists with pain and pianists without pain related to piano-playing. We generated the histograms at the end of the imaging session after participants had finished playing the piano exercises. The x-axis shows the temperature range while the y-axis shows the number of pixels associated with each temperature.

We selected a representative sample of the histograms, shown in figures 4.10, 4.11, 4.12, 4.13, 4.14, and 4.15. Figures 4.10 and 4.11 show examples of the histograms of the hand temperatures for pianists without pain, and figures 4.12 and 4.13 show examples of the histograms of the hand temperatures for pianists with pain. Figure 4.14 shows the histogram of the hand temperatures for participant P17, who did not suffer from pain related to piano-playing. Figure 4.15 shows the histogram of participant P18 who did not have any pain during our experiment, and only suffers from pain after playing for a long time. The histograms for the remaining participants are shown in appendix C.



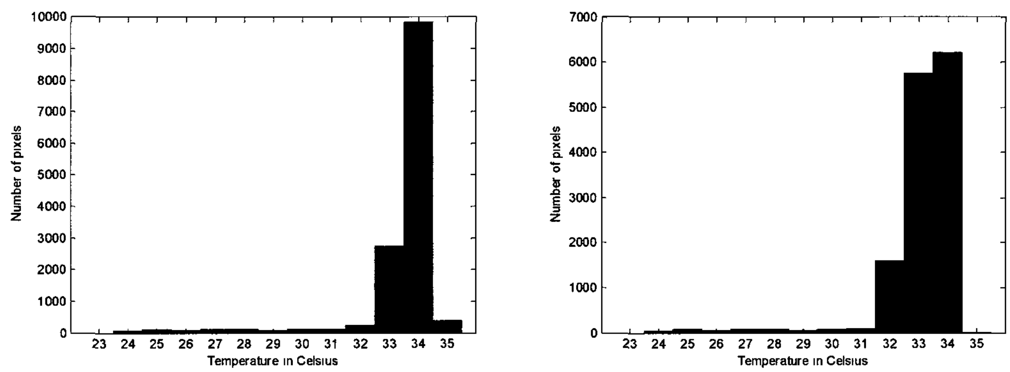
(a) (b)

Figure 4.10: Histogram for participant P14 (pianist without pain), (a) right hand dorsal, and (b) left hand dorsal.



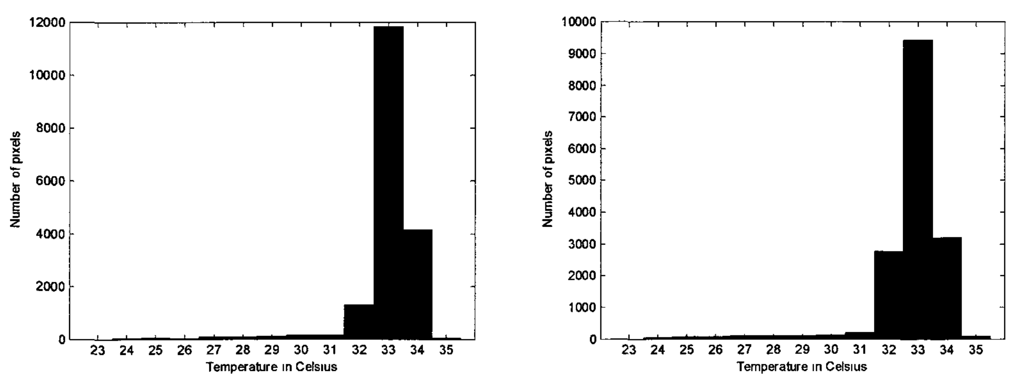
(a) (b)

Figure 4.11: Histogram for participant P16 (pianist without pain), (a) right hand dorsal, and (b) left hand dorsal.



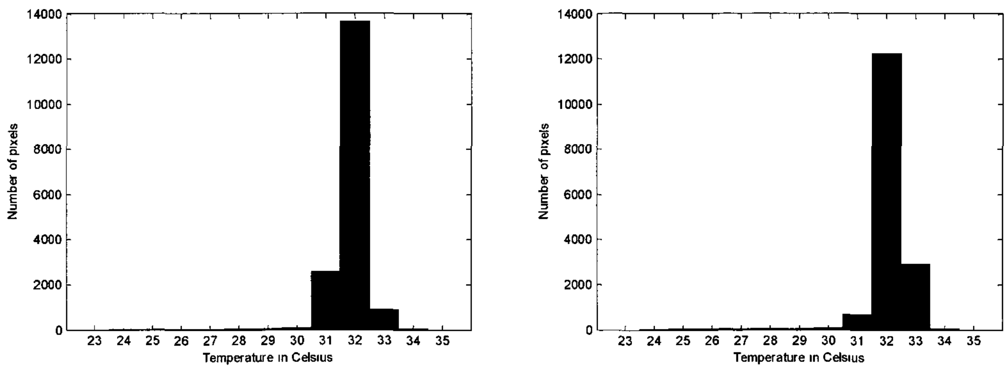
(a) (b)

Figure 4.12: Histogram for participant P15 (pianist with pain), (a) right hand dorsal, and (b) left hand dorsal.



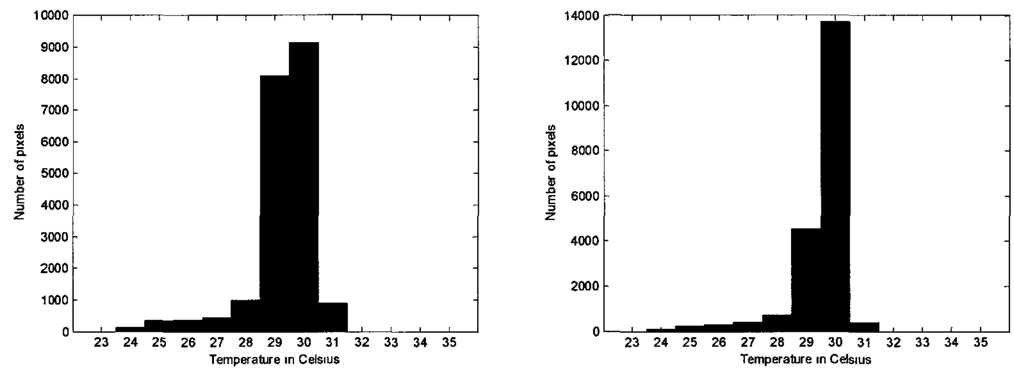
(a) (b)

Figure 4.13: Histogram for participant P19 (pianist with pain), (a) right hand dorsal, and (b) left hand dorsal.



(a) (b)

Figure 4.14: Histogram for participant P17 (pianist without pain) who might be at a risk of developing pain related to piano-playing, (a) right hand dorsal, and (b) left hand dorsal.



(a) (b)

Figure 4.15: Histogram for participant P18, the subject did not have pain during the experiment but suffers from pain after playing for a long time: (a) right hand dorsal, and (b) left hand dorsal.

The histogram plots show that pianists without pain have higher pixel counts at lower temperature range compared to pianists with pain related to piano-playing. We had a contradictory case, participant P17, who might be at risk of developing pain due to long hours of practice. We also plotted the histogram for participant P18, who indicated that the pain starts after playing for long hours and did not have any pain at the time of the imaging session; the histogram shows that there are more pixels at the low temperature values than the high temperature values. Also, the histograms for the pianists with pain related to piano-playing tend to shift towards the right (the high temperature values). In general histograms are a good visual assessment tool to examine the temperature within the region of interest, but we need a larger sample to confirm our findings.

4.5 Average Temperature Calculations

We calculated the average temperature for the hands from the different temperature measurements that were taken at different times for each participant in our 2010 data group. We wanted to see if we could differentiate the two groups based on the average temperature of the upper extremities.

Pianists without pain related to piano-playing, with the exception of participant P17, had lower temperatures compared to pianists without pain. Participant P17 practices every day for 1 to 4 hours and might be at risk of developing pain. Another exception was participant P18 (pianist with pain), who indicated that the pain starts after playing the piano for long hours. Participant P18 did not have any pain during the experiment and this might explain the low average temperature compared to participants with pain. Table 4.3 shows the average temperature for the hands for pianists without pain, while table 4.4 shows the average temperature for the hands for pianists with pain. For abbreviation purposes we use the term RHP for right hand palmar, LHP for left hand palmar, RHD for right hand dorsal, LHD for left hand dorsal, RAA for right arm anterior, LAA for left arm anterior, RAD for right arm dorsal, and LAD for left arm dorsal.

	RHP (degree Celsius)	RHD (degree Celsius)	Average temp for right hand (degree Celsius)	LHP (degree Celsius)	LHD (degree Celsius)	Average temp for left hand (degree Cels
P14	28.9	28.8	28.8	28.4	28.4	28.4
P16	29.3	27.9	28.67739	29.3	27.8	28.5
P17	31.2	30.8	31.0	32.0	30.6	31.3

Table 4.3: The average temperature calculated for the right hand and the left hand for pianists without pain related to piano-playing.

	RHP	RHD (degree Celsius)	Average temp for right hand (degree Celsius)	LHP (degree Celsius)	LHD (degree Celsius)	Average temp for left hand (degree Celsius)
P12	31.6	30.9	31.3	32.1	31.5	31.8
P13	32.0	30.8	31.4	32.4	31.4	31.9
P15	33.4	32.4	32.9	32.8	32.0	32.4
P18	30.9	30.3	30.6	30.7	29.9	30.3
P19	33.37	32.1	32.7	32.5	31.7	32.1
P20	32.6	32.5	32.5	32.5	32.3	32.4

Table 4.4: The average temperature calculated for the right hand and the left hand for pianists with pain.

Next, we calculated the average temperature for the lower arms, anterior and dorsal. The results are shown in table 4.5 for pianists without pain and in table 4.6 for pianists with pain. We did not see any difference between pianists without pain and pianists with pain based on the lower arms' average temperature.

	RAA(L) (degree Celsius)	RAD(L) (degree Celsius)	Lower right arm average temperature (degree Celsius)	LAA(L) (degree Celsius)	LAD(L) (degree Celsius)	Lower left arm average temperature (degree Celsius)
P14	31.4	31.0	31.2	31.3	30.7	31.0
P16	29.8	29.9	29.8	30.0	29.5	29.8
P17	31.1	31.9	31.5	32.0	32.0	32.1

Table 4.5: Average temperature calculated for the lower arms for pianists without pain.

	RAA(L) (degree Celsius)	RAD(L) (degree Celsius)	Lower right arm average temperature (degree Celsius)	LAA(L) (degree Celsius)	LAD(L) (degree Celsius)	Lower left arm average temperature (degree Celsius)
P12	32.3	31.1	31.7	31.9	31.3	31.6
P13	30.8	31.3	31.1	31.0	31.2	31.1
P15	31.2	31.4	31.3	31.1	31.0	31.0
P18	31.2	31.2	31.2	31.3	30.8	31.0
P19	31.5	30.8	31.1	31.8	31.6	31.7
P20	31.3	31.0	31.1	31.0	30.5	30.8

Table 4.6: Average temperature calculated for the lower arms for pianists with pain.

Finally, we calculated the average temperature for the upper arms, anterior and dorsal. The results are shown in table 4.7 for pianists without pain and in table 4.8 for pianists with pain. Again, we did not see any difference between pianists with pain and pianists without pain based on the upper arms' average temperature.

	RAA(U) (degree Celsius)	RAD (U) (degree Celsius)	Upper right arm average temperature (degree Celsius)	LAA(U) (degree Celsius)	LAD (U) (degree Celsius)	Upper left arm average temperature (degree Celsius)
P14	31.9	29.4	30.6	31.5	28.9	30.2
P16	31.1	28.7	29.9	31.0	28.6	29.8
P17	31.4	31.2	31.3	32.0	31.2	31.6

Table 4.7: Average temperature calculated for the upper arms for pianists without pain.

	RAA(U) (degree Celsius)	RAD (U) (degree Celsius)	Upper right arm average temperature (degree Celsius)	LAA(U) (degree Celsius)	LAD (U) (degree Celsius)	Upper left arm average temperature (degree Celsius)
P12	31.4	31.1	31.3	31.6	30.9	31.2
P13	31.0	28.9	29.9	31.1	28.6	29.8
P15	30.8	29.1	30.0	30.7	28.8	29.7
P18	31.3	30.0	30.7	31.1	29.2	30.2
P19	30.9	28.3	29.6	31.2	28.5	29.9
P20	31.1	29.5	30.3	31.1	29.1	30.1

Table 4.8: Average temperature calculated for the upper arms for pianists with pain.

Based on our calculation for the hands and the arms' average temperature after the end of the imaging session, we found that the hands are the most affected in the upper extremity by physical stress related to piano-playing. A high average temperature for a pianist without pain might be a good indication that he/she is at a risk of developing pain.

4.6 Temperature Variation over Time

To visualize the difference in temperature variations between individuals, we plotted the right hand dorsal and the left hand dorsal temperatures over the experiment time for each participant. Figures 4.16 and 4.17 show the temperature plots for data collected in 2010 by S. Mohamed, and figures 4.18 and 4.19 show the temperature plots for data collected in 2006 by C. Herry.

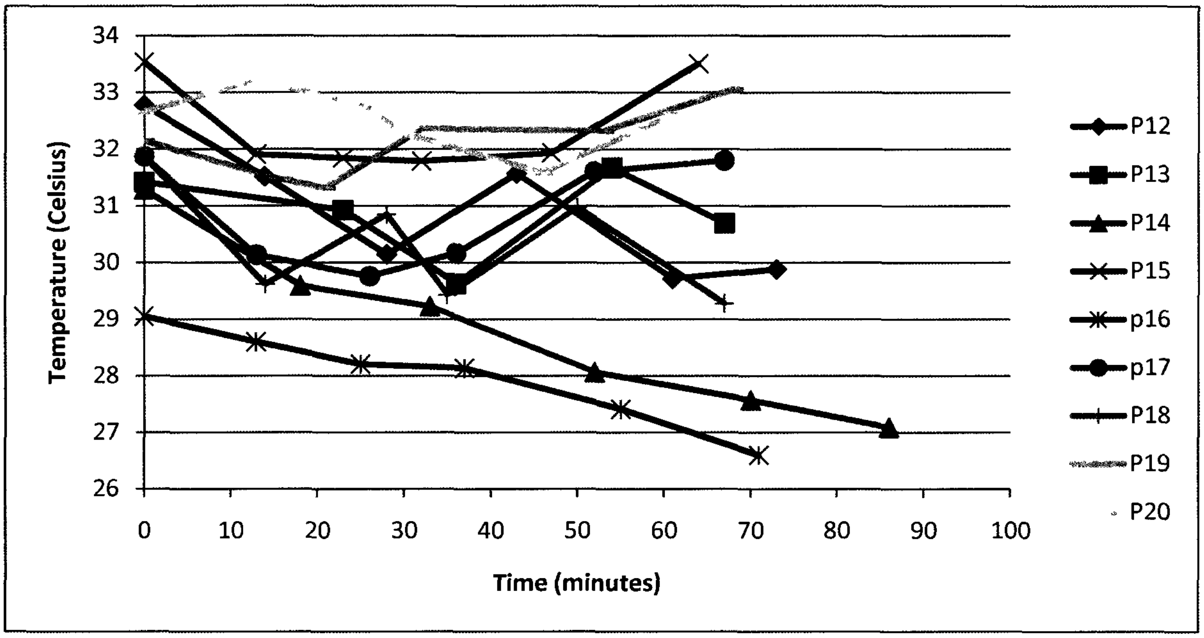


Figure 4.16: Temperature variation over time for the right hand dorsal for the images collected in 2010. Participants P14, P16, and P17 did not suffer from pain related to piano-playing.

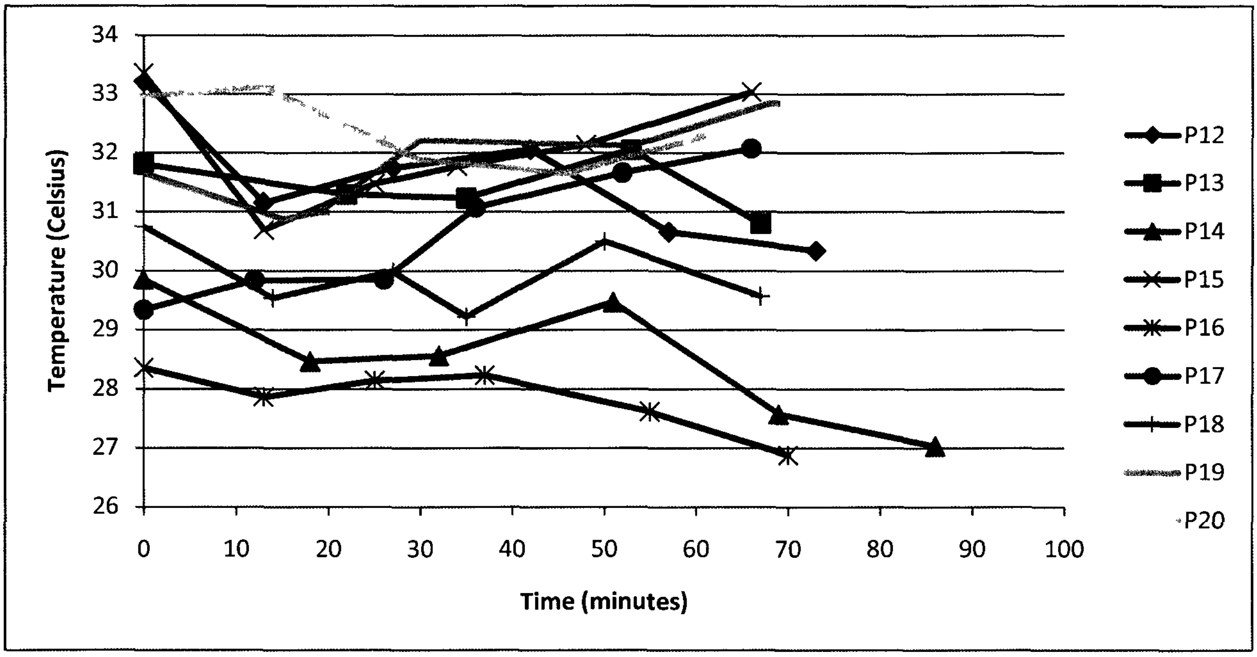


Figure 4.17: Temperature variation over time for the left hand dorsal for the images collected in 2010. Participants P14, P16, and P17 did not suffer from pain related to piano-playing.

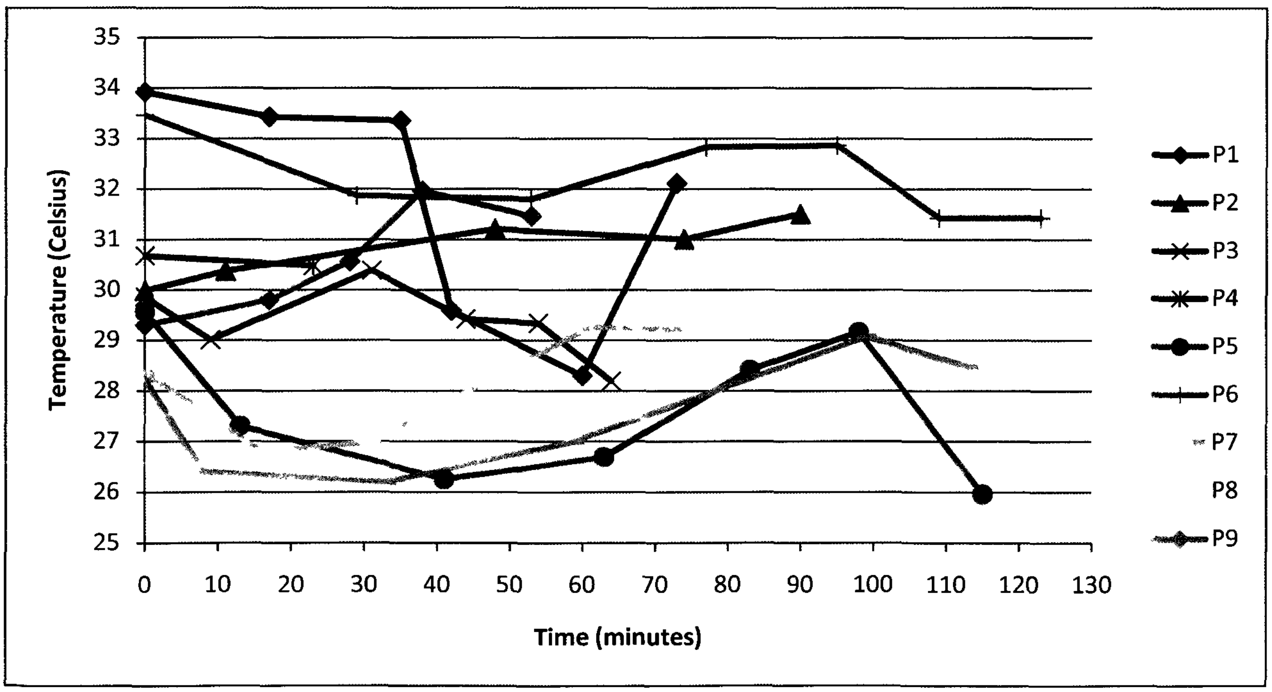


Figure 4.18: Temperature variation over time for the data collected in 2006 for right hand dorsal. P6 had pain related to piano-playing, while P1 had sweaty hands.

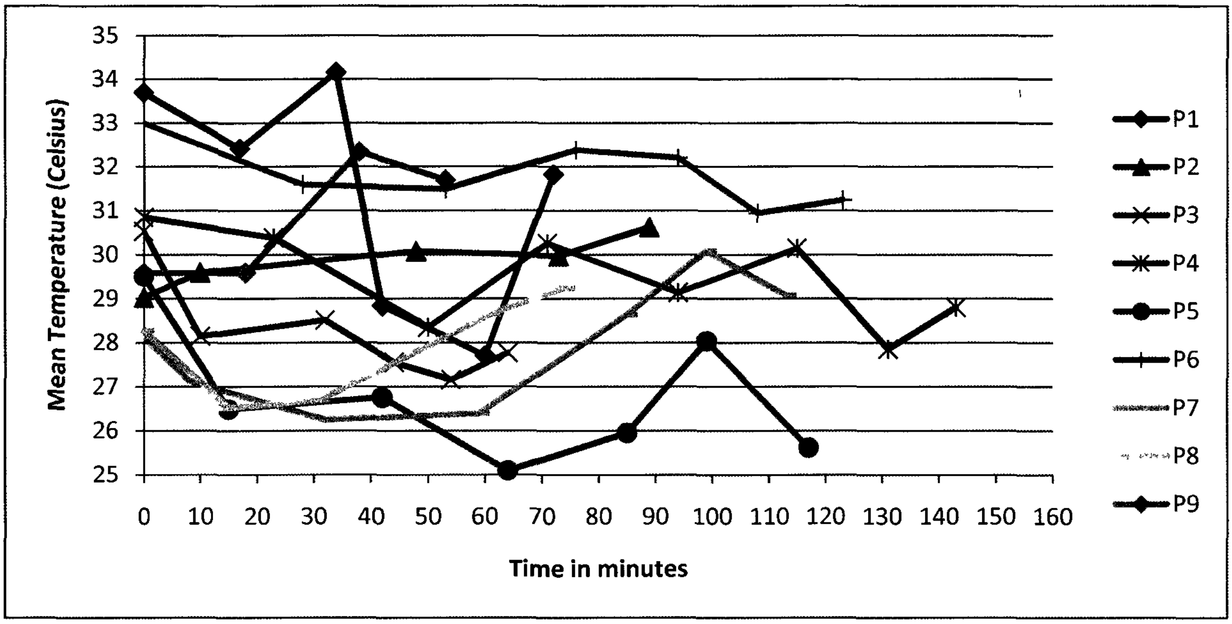


Figure 4.19: Temperature variation over time for the data collected in 2006 for the left hand dorsal. P6 had pain related to piano-playing, while P1 had sweaty hands.

We concluded, based on our graphs, that participants who suffer from pain related to piano-playing have higher temperature variation over time than the ones who do not suffer from pain related to piano-playing. It is also hard to receive meaningful results without having a systematic protocol, which is the case for the data collected in 2006 by C. Herry.

4.7 Temperature over Time Plot for Individuals

We plotted the temperature over time for the hands and arms for each subject to observe the temperature pattern for their hands and arms. Figure 4.20 shows an example of the temperature plot for a participant without pain, while figure 4.21 shows an example of the temperature plots for a participant with pain. Participant P13 who had pain during the experiment showed a more complicated pattern as shown in figure 4.22. The temperature plots for the remaining participants are given in appendix C.

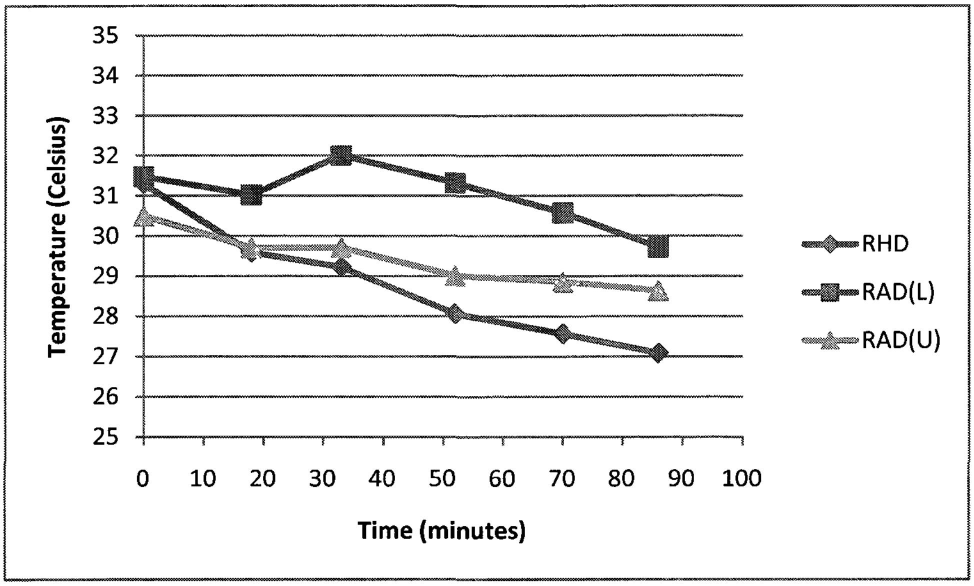


Figure 4.20: Temperature over time plot for the right upper extremity for participant P14, who did not experience pain. The hand temperature is lower than the arm temperature.

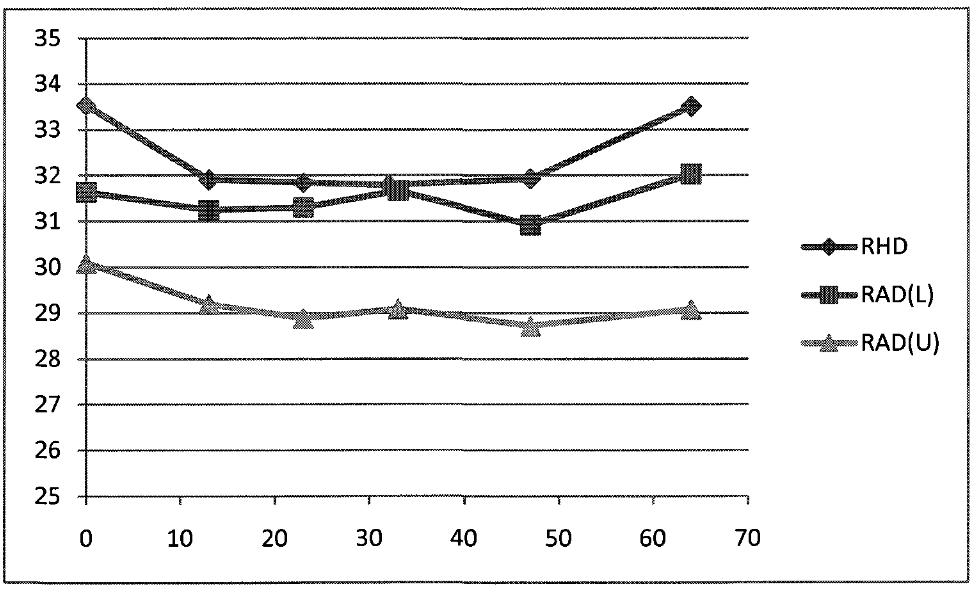


Figure 4.21: Temperature over time plot for the right upper extremity for participant P15, who experienced pain related to piano-playing. The hand temperature is higher than the arm temperature.

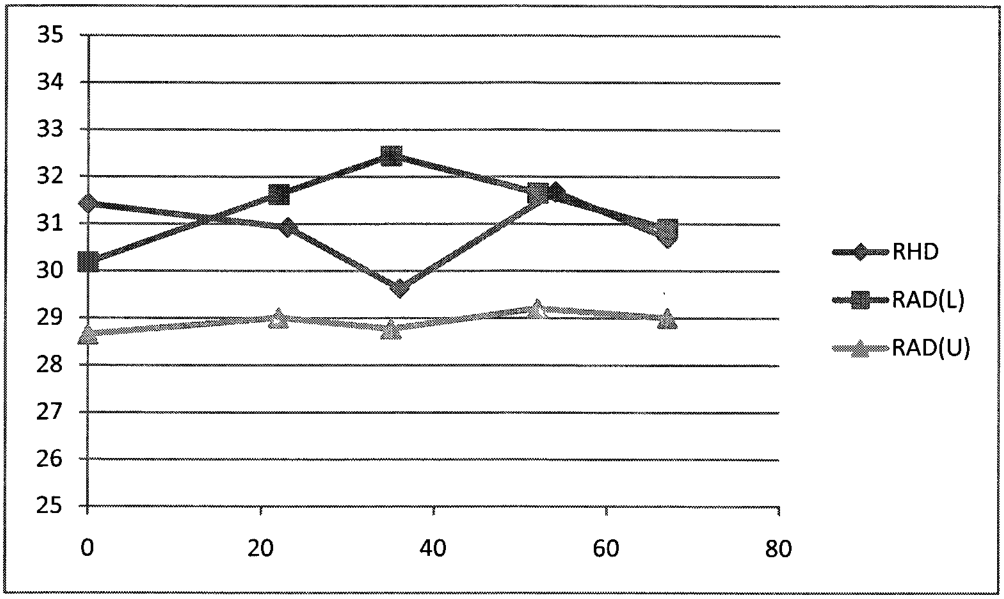


Figure 4.22: Temperature over time plot for the left upper extremity (dorsal) for participant P13, who experienced pain at the time of the experiment. The hand temperature and the arm temperature do not have a consistent relationship.

Next we calculated the difference between the hand temperatures and the arm temperatures (right hand dorsal minus lower arm dorsal) for participants P12 to P20 and plotted them as shown in figure 4.23.

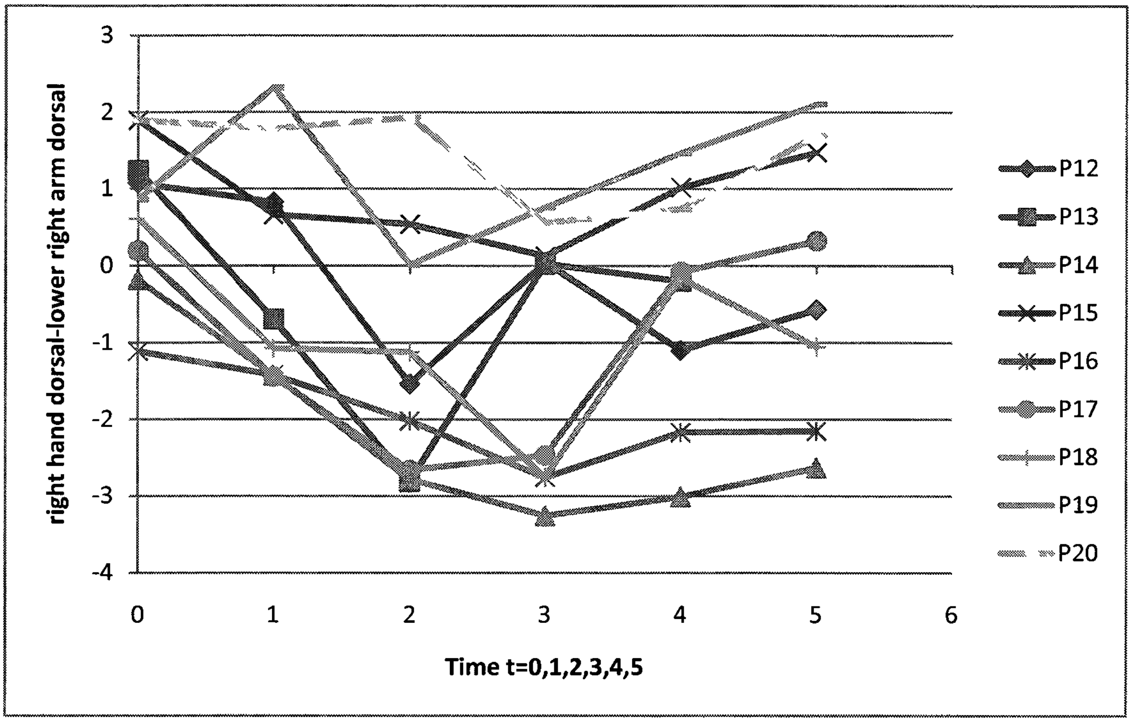


Figure 4.23: Temperature difference (right hand dorsal minus lower arm dorsal) for participants P12 to P20. The temperature plot tends to shift towards the positive part of the y-axis for pianists with pain.

Pianists with pain or those who are at risk of developing pain have high hand temperatures compared to their arms due to the physical demand on the hands. By plotting the temperature of the hands and arms over time for each participant, we found that pianists without pain have low hand temperatures compared to their upper arms. We also found that subjects with pain have the reverse pattern.

4.8 Discussion

Medical infrared imaging can be used to show the difference between pianists with pain and pianists without pain. It can also identify subjects who are at risk of developing pain related to piano-playing. However, a strict protocol must be followed and the regions of interest must be chosen carefully to reflect temperature variations. Also the pain frequency should be taken into consideration. Some people experience pain at different parts of their hands/arms, at different times; for some, there is always pain accompanied by piano-playing, while for others, the pain comes randomly or after playing for long hours. Therefore, it is important to classify the data carefully in order to produce meaningful results. In our experiment, a difficult case was participant 18, who did not have any problems completing our experiment, but who would have trouble completing a longer experiment. Also pianists without pain were more capable of performing the physically demanding piano exercise, while pianists with pain were only capable of playing the physically demanding exercise for a few seconds. This might result in elevating the temperature of the hands for the pianists without pain, making it more difficult to distinguish between the two groups.

Some people might be at risk of developing pain due to long hours of practice. One example is subject 17, who practices for a long time and did not report any pain related to piano-playing, but whose hand temperatures are high compared to the subjects who did not have any pain related to piano-playing.

The questionnaire informed us on which pianists have pain and which pianists did not have pain related to piano playing. We expected no or very little variation in the participants hand temperature before they started playing the piano, but we were surprised to see that there was a statistical difference between pianists with pain and pianists without pain even before they started playing the piano. This could be the sign of overworked muscles as the result of practicing the piano regularly. Also, the temperature plots show that the pianists with pain have higher hand temperatures than their arms due to the physical demand put on the hands during piano-playing.

Histograms are a good visualization tool; the histogram for pianists with pain tends to shift towards the high temperature values. Also, the histogram shows that there are more pixels at the high temperature range than the lower temperature range for pianists with pain or those at risk of developing pain.

Finally, we could not find any difference between the participants who do warm-ups and those who do not do any warm-ups. That might be due to the fact that we did not ask them to do their usual warm-ups; they were only instructed to follow our protocol.

Chapter 5

Conclusions and Future Work

This chapter summarizes our findings, contributions to knowledge, and proposes future work.

5.1 Conclusion

Pain is hard to quantify because it is a subjective term and very dependent on a person's pain threshold. Many piano players believe that pain is a necessary part of playing the piano in order to achieve the right performance. Extending the tendons and the ligaments of the hands beyond their mechanical tolerance can cause permanent damage to them. It is important for piano players not to stress their hands during piano-playing and pay attention to the position of their hands and of their body to reduce the stress on the hands.

Medical infrared imaging is a non-invasive technique that records the body temperature and produces a thermal map of the body. Advances in infrared technology have made it possible to use infrared imaging to study diseases that produces a change in the body temperature such as breast cancer, rheumatoid arthritis, and pain. Infrared imaging is a useful technique for long term studies because it does not produce any ionising radiation. The success of the infrared imaging depends on the following: a strict protocol, controlling the environment, and choosing the proper regions of interest for analysis.

There is a correlation between heat and pain due to piano playing which was shown in the difference in the mean temperature of the hands between pianists with pain and pianists without pain. Our statistical analysis showed that pianists with pain can be differentiated from pianists without pain based on the hand temperature measurements.

There is a variation in the hand temperatures among people, and variation of the hand temperature over time for each individual. Despite the complexity of observing the change in temperature over time, we were able to observe these variations. The temperature over time plots showed that pianists with pain have higher hand temperatures than pianists without pain. Also, the temperature over time plots for the hand and arm temperatures for individuals showed that pianists with pain put more stress on their hands than their arms. This could be used as an early detection tool indicating that the participant is at risk of developing pain.

Histograms can be used as a visual tool to examine the heat content within the regions of interest. By plotting the histogram of the hands' mean temperatures for the participants, we observed that participants who suffered from pain related to piano-playing in general had more pixels at a high temperature range than those who did not. We need more participants to draw a stronger conclusion. In addition, the histogram tends to shift towards the right or the high temperature range for participants with pain.

5.2 Contributions to knowledge

1. The first contribution to knowledge was the completion of the thesis objective, that there is a correlation between heat and pain induced by piano-playing. Infrared imaging can

differentiate between the participants who suffer from pain related to piano-playing and participants who do not suffer from pain related to piano-playing. Our statistical analysis showed that the group without pain can be differentiated from the group with pain related to piano-playing.

2. The second contribution to knowledge was the identification of the hand as the best part of the upper extremity to identify players with pain. Our systematic and statistical analysis showed that the hand temperature is the best measurement to discriminate between participants with pain and the participants without pain related to piano-playing. Participants who suffered from pain related to piano-playing had elevated hand temperatures. This manifested in two ways: they had higher hand temperatures than participants who did not suffer from pain related to piano-playing; they also had higher hand temperatures than their lower and upper arm temperatures. This indicated that they were stressing their hands more than their arms, resulting in pain during playing the piano.

3. Our third contribution is our systematic approach. This research work confirmed that our new protocol and experimental design led to meaningful results and is a good template for further studies of piano players and other types of musicians in the future. Recruiting participants with and without pain related to piano-playing, designing the protocol, the experimental set up, and gathering the data provided a systematic approach that can be used for further studies related to piano-playing.

5.3 Future work

It would be useful to have a follow up imaging session for the participants. It will be beneficial to know if the participant who did not suffer from pain related to piano-playing but had high temperature average ever developed pain. It would also be good to monitor the participant who indicated that the pain starts after long hours of practice. However, it might be difficult to do follow up if the participants were not informed that they would be contacted again.

Our study included participants with a wide age range and various piano- playing skills. However, we feel that a more controlled study that focuses on a specific age group with the same piano-playing skills may produce more solid results.

Professional piano players, who practice for very long hours every day, might be at a higher risk of developing pain than those who do not practice for long hours every day. It is important to study the high risk group closely to identify the potential of developing pain related to piano-playing. Some studies have indicated that the size of the hand might be a factor in developing pain related to piano-playing because people with small hands could be extending their fingers beyond their mechanical capacity to achieve a good quality sound.

We propose that a future study be longitudinal and controlled for age and experience. For example, the researchers would image a group of first year piano students who are at the same level of piano-playing after playing specific piano exercises. Then the researchers would continue imaging the students as they advance in their music program. The study should include equal numbers of males and females. In addition, it will be beneficial to perform image analysis of pianists without pain early in their music career and to follow them for some years to assess if they develop pain related to piano-playing.

It is still a challenge to develop a system that predicts if the person will or will not develop pain later in life if they continue practicing the piano for long hours. By applying more controlled longitudinal studies, a heat or cooling pattern might show among those who at a risk of developing pain related to piano-playing. It is possible that pain develops through a poor technique. The relationship between technique and pain could be studied by using visual cameras to observe the technique and correlating this with temperature measurements. A better understanding of the problem could lead to early detection of overuse syndrome or repetitive strain injuries. This could benefit office and factory workers as well as musicians.

Finally the background extraction and the region of interest selection could be fully automated to increase the quality and the speed of the segmentation process. The automated process would result in accurate detection of edges and regions in the images which would accelerate the data extraction stage. This could encourage the extension of the study to more parts of the body such as the neck and the back.

References

Adea, Cynthia. *Severity of illness measures of rheumatoid arthritis using thermal infrared imaging*. Master's thesis, Carleton University: Ottawa, 2009.

Alford, Robert R., and Andras Szanto. "Orpheus wounded: The experience of pain in the professional worlds of the piano." *Theory and Society* 25 (1996):1-44.

Anbar, Michael. "Clinical thermal imaging today: shifting from phenomenological thermography to pathophysiolocially based thermal imaging." *IEEE Engineering in Medicine and Biology Magazine* 17, no. 4 (1998): 25-33.

Anbar, Michael. "Objective assessment of clinical computerized thermal images." In *Medical Imaging V: Image Processing, Proceedings of SPIE* 1445, pages 479-484, 1991.

Aubry-Frize, M. "The thermographic detection of pain." In *Proceedings of the 3rd Canadian Clinical Engineering Conference,* pages 82-83. Saskatoon, Canada, September 1983.

Bejjani, Fadi Joseph, Glenn M. Kaye, and Melody Benham. "Musculoskeletal and neuromuscular conditions of instrumental musicians." *Archives of Physical Medicine and Rehabilitation* 77, no. 4 (1996): 406-413.

Bengston, Keith A., and Ann H. Schutt. "Upper extremity musculoskeletal problems in musicians: a follow-up survey." *Medical Problems of Performing Artists* 7, no. 2 (1992): 44-47.

Bird, H. A., E. F. Ring, and P. A. Bacon. "A thermographic and clinical comparison of three intra-articular steroid preparations in rheumatoid arthritis." *Annals of Rheumatic Diseases* 38, no.1 (1979): 36-39.

Bovik, Alan Conard. *The Essential Guide to Image Processing*. San Diego: Elsevier Inc, 2009.

Burnay, S. G., T. L. Williams, and C. H. Jones. *Applications of Thermal Imaging*. Bristol: IOP Publishing, 1988.

Bragge, Peter, Andrea Bialocerkowski, and Joan McMeeken. "A systematic review of prevalence and risk factors associated with playing–related musculoskeletal disorders in pianists." *Occupational Medicine* 56, no. 1 (2006): 28-38.

Campbell, Neill A., Jane B. Reece, Martha R. Taylor, and Eric J. Simon. *Biology Concepts and Connections.* San Francisco: Pearson Education Inc, 2006.

Collins, A J, and J A Cosh. "Temperature and biochemical studies of joint inflammation. A preliminary investigation." *Annals of Rheumatoid Diseases* 29, no.4 (1970): 386-391.

Collins, A. J., E. F. Ring, J. A. Cosh, et al. "Quantitation of thermography in arthritis using multi-isothermal analysis. I. The thermographic index." *Annals of Rheumatoid Diseases* 33, no. 2 (1974): 113-115.

Dawson, William J. "Upper extremity overuse in instrumentalists." *Medical Problems of Performing Artists*16, no. 2 (2001): 66-71

Devereau, M. D., G. R. Parr, D. P. Thomas, and B. L. Hazleman. "Disease Activity Indexes in Rheumatoid Arthritis: a Prospective Comparative Study using Thermography." *Annals of the Rheumatic Diseases* 44, no. 7 (1985): 434-437.

Diakides, N. A. and J. D. Bronzino, Eds. *Medical infrared imaging.* New York: CRS Press, 2008.

FLIR Systems. *ThermaCAM Researcher User's manual*. Sweeden: Publ. No.1 558 071 Rev. A52, 2004.

Frize, Monique, Christophe Herry, and Roger Roberge. "Processing of thermal images to detect breast cancer: comparison with previous work." In *Proceedings of the second joint EMBS/BMES conference,* pages 1159-1160. Houston, USA, October 23-26, 2002.

Frize, Monique, Christophe Herry, and Nathan Scales. "Processing thermal images to detect breast cancer and assess pain." In *Proceedings of the 4th annual IEEE EMBS Special Topic Conference on Information technology Applications in Biomedicine*, pages 234-237. Birmingham, UK, April 24-26, 2003.

Fry, H. J. "Prevalence of overuse (injury) syndrome in Australian music schools." *British Journal of Industrial Medicine* 44, no. 1 (1987): 35-40.

Fry, H. J. H. "The treatment of overuse syndrome in musicians." *Journal of the Royal Society of Medicine* 81, no. 10 (1988): 572-575.

Hassan , M. , D. Hattery, V. Chernomordik, K. Toda, K. Fukuhara, D. Mittak, J. Rowan, J. Shah, L. Gerber, R. Dionne, I. Kopin, and A. H. Gandjbakhche. "Infrared thermographic imaging for the assessment of temperature asymmetries in reflex sympathetic dystrophy." In *Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society,* pages 1102-1105. Cancun, Mexico, September 17-21, 2003.

Head, Jonathan F., Charles A. Lipari, Fen Wang, and Robert L. Elliot. "Image analysis of digitized infrared images of the breasts from a first generation infrared imaging system." In *Proceedings of the 19th International Conference- IEEE Engineering in Medicine and Biology Society,* pages 681-684. Chicago, USA, October 30-November 2, 1997.

Heming, M. J. E. “Occupational injuries suffered by classical musicians through overuse.” *Clinical Chiropractic* 7, no. 2 (2004): 55-66.

Herry, Christophe. *Quantitative assessment of pain through clinical digital infrared thermal imaging*. Master’s thesis, Carleton University: Ottawa, 2002.

Herry, C. L., and M. Frize. Quantitative assessment of pain-related thermal dysfunction through clinical digital infrared thermal imaging. *BioMedical Engineering OnLine* 3, no. 19, June 2004.

Herry, L. Christophe, Monique Frize, and Rafik Goubran. 2008. “Search for abnormal thermal patterns in clinical thermal infrared imaging.” In *IEEE International Workshop on Medical Measurements and Applications*, pages 61-65. Ottawa, Canada, 9-10 May, 2000.

Herry, Christophe L., Rafik A. Goubran, and Monique Frize. “Improving the detection and localization of anatomical landmark points in infrared images using symmetry and region specific constraints.” In *IEEE International Instrumentation and Measurement Technology Conference*, pages 1306 – 1311. Victoria, Canada, 12-15 May, 2000.

Herry, C. L., and M. Frize. 2002. Digital processing techniques for the assessment of pain with infrared thermal imaging. In *Proceedings of the Second Joint EMBS/BMES conference*, pages 1157-1158. Houston, USA, October 23-26, 2002.

Herry, C. L., M. Frize, R. A. Goubran, and G. Comeau. Evolution of the surface temperature of pianists’ arm muscles using infrared thermography. In *Proceedings of the 27th Annual Conference of the IEEE-EMBS Engineering in Medicine and Biology Society,* pages1687-1690. Shanghai, China, 17-18 Jan, 2006.

Hochberg, Fred H., Robert D. Leffert, Heller Matthew D., and Lisle Merriman. Hand difficulties among musicians. *The Journal of the American Medical Association* 249, no. 14 (1983): 1869-1873.

Hoppmann, Richard A., and Rodney R. Reid. "Musculoskeletal problems of performing artists." *Current Opinion in Rheumatology* 7, no. 2 (1995): 147-150.

Hooshmand, H., M. Hashmi, and E. M. Phillips. "Infrared thermal imaging as a tool in pain management-an 11 year study, part 1 of II." *Thermology International* 11, no. 2 (2001): 53-65.

Houdas, Y., and E. F. J. Ring. *Human body temperature: its measurement and regulation.* New York : Plenum Press, 1982.

Jones, Bryan F. December 1998. "A Reappraisal of the Use of Infrared Thermal Image Analysis in Medicine." *IEEE Transactions on medical imaging* 17, no. 6 (1998):1019- 1027.

Jones, B. F., and P. Plassmann. "Digital Infrared Thermal Imaging of the Human Skin." *Engineering in Medicine and Biology Magazine* 21, no. 6 (2002): 41- 48.

Kim, Young-Soo, and Yong-Eun Cho. "Correlation of pain severity with thermography." In *IEEE 17th annual conference Engineering in Medicine and Biology Society,* pages1699-1700. Montreal, Canada, 20-23 September, 1995.

Koay, Jessica. *Quantitative analysis of infrared images for early breast cancer detection.* Master's thesis, Carleton University: Ottawa, 2004.

Laccetti, Margaret Saul, and Mary K. Kazanowski. *Pain management.* Sudbury, Mass.: Jones and Bartlett Publishers, 2008.

Lederman Richard. "Neuromuscular and musculoskeletal problems in instrumental musicians." *Muscle and Nerve* 27, no. 5 (2003): 549-561.

LeRoy, Pierre, Cynthia R. Christian, and Roseanne Filasky. "Diagnostic thermography in low back pain syndromes." The Clinical Journal of Pain 1, no. 1 (1985): 4-13.

Merskey, Harold, and Nikolai Bogduk. *Classification of chronic pain: descriptions of chronic pain syndromes and definitions of pain terms*. Seattle: IASP Press, 1994.

Ng, E.Y.-K. "A review of thermography as promising non-invasive detection modality for breast tumor." *International Journal of Thermal Sciences* 48, no. 5 (2009): 849-859.

Ohashi, Y., and I. Uchida. "Applying dynamic thermography in the diagnosis of breast cancer." *IEEE on Engineering in Medicine and Biology Magazine* 19, no. 3 (2000):42-51.

Pearl, David. *Piano exercises for dummies*. New Jersey: Wiley Publishing Inc, 2008.

Peacina, Marko M., and Bojanic Ivan. *Overuse injuries of the musculoskeletal system*. Florida: CRC Press LLC, 2004.

Ring, F. "Quantitative Thermal Imaging in Rheumatology." In *Medicine and Biology Society, Engineering Advances: New Opportunities for Biomedical Engineers. Proceedings of the 16th Annual International Conference of the IEEE,* pages 50a-54a. November 1994

Ring, Francis J. "Criteria for thermal imaging in medicine." In *IEEE 17th Annual Conference on Engineering in Medicine and Biology Society,* pages 20-23. September1995, 2:1697-1698

Ring, E.F.J. "Progress in the measurement of human body temperature." *IEEE Engineering in Medicine and Biology Magazine* 17, no. 4 (1998):19-24.

Ring, E. F. J., and K. Ammer. "The technique of infrared imaging in medicine." *Thermology International* (2000).

Ring, F. The historical development of thermal images in medicine. *Rheumatology* 43, no. 6

(2004): 800-802.

Ring, E. F. J. "The historical development of temperature measurement in medicine." *Infrared Physics and Technology* 49, no. 3 (2007): 297-301.

Salisbury, R. S., G. Parr, M. De Silva, B. L. Hazleman, and D. P. Page-Thomas. "Heat distribution over normal and abnormal joints: thermal pattern and quantification." *Annals of the Rheumatoid Diseases* 42, no. 5 (1983): 494-499

Sandor, Gregory. *On Piano Playing.* New York: Shrimer Books, 1981.

Scales, N., C. Herry, and M. Frize. 2004. Automated image segmentation for breast analysis using infrared images. In *Proceedings of the 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society,* pages 1737-1740. San Francisco, USA, September 1-5, 2004.

Schlessinger, M. *Infrared Technology Fundamentals*. New York: Marcel Dekker. 1995.

Shields, Nora, and Sara Dockrell. "The prevalence of injuries among pianists in music schools in Ireland." *Medical Problems of Performing Artists* 15, no. 4 (2000):155-161.

Smet, L. De, H. Ghyselen, and R. Lysens. "Incidence of overuse syndromes of the upper limb in young pianists and its correlation with hand size, hypermobility and playing habits." *Annales de Chirurgie de la Main et du Membre Supérieur* 17, no. 4 (1998): 309-313.

Sokka, Tuulikki. "Assessment of pain in patients with rheumatic diseases." *Best Practice and Research* 17, no. 3 (2003): 427-449.

Tortora, Gerard J., and Bryan Derrickson. *Principles of Anatomy and Physiology.* New Jersey: John Wiley and Sons Inc, 2006.

Tubiana, Raoul, and Peter C. Amadio. *Medical problems of the instrumentalist musician.* London: Martin Dunitz Ltd, 2000.

Uematsu, Sumio. "Symmetry of skin temperature comparing one side of the body to the other." *Thermology* 1, no. 1 (1985): 4-7.

Uematsu, Sumio, David H. Edwin, William R. Jankel, Joseph Kozikowski, and Michael Trattner. "Quantification of thermal asymmetry Part 1: Normal values and reproducibility." *Journal of Neurosurgery* 69, no. 4 (1988): 552-555.

Uematsu, Sumio, David H.Edwin, William R. Jankel, David H. Edwin, Won Kim, Joseph Kozikowski, Arthur Rosenbaum, and Donlin M. Long. "Quantification of thermal asymmetry Part 2: Applications in low-back pain and sciatica." *Journal of Neurosurgery* 69, no. 4 (1988): 556-561.

Vant, Christianne. *Driving Point Impedance Measurements During Piano Playing.* Master's thesis, Carleton University: Ottawa, 2007.

Wall, Patrick D., and Ronald Melzack. *Textbook of pain.* Edinburgh: Churchill Livingstone, 1999.

Wolf, F. Gregory, Martha S. Keane, Kenneth D. Brandt, and Ben M. Hillberry. "An investigation of finger joint and tendon forces in experienced pianists." *Medical Problems of Performing Artists* 8, no. 3 (1993): 84-95.

Zaza, Christine. "Playing-related musculoskeletal disorders in musicians: a systematic review of incidence and prevalence." *Canadian Medical Association Journal* 158, no. 8 (1998): 1019-1025.

Appendix A

Information package

Each participate was given the following information package highlighting the purpose of the research, the protocol to prepare for the imaging session, the consent form, and the questionnaire.

A.1 Information letter

Research project title:
Prospective study of playing-related musculoskeletal disorders linked to the regular practice of the piano, with infrared thermography.

Researchers/investigators:

(a) Dr. Monique Frize, professor, School of Information Technology and Engineering, University of Ottawa.
(b) Dr. Gilles Comeau, professor, Music School, University of Ottawa.
(c) Safaa Mohamed, MASc. Candidate, Biomedical Engineering, Department of Systems and Computer Engineering, Carleton University.

We would like you to participate in a research project. This form will give you all the necessary information and will explain what we expect from you. One of the researchers will also talk to you to explain the research project and answer any question you might want to ask. Please read the following information carefully and please do not hesitate to ask questions on anything you do not understand fully before you choose to participate in this project.

Your participation is entirely voluntary and you can choose not to participate without any penalty or loss of benefits to which you would have been entitled otherwise. You may bring home a copy of this information letter so that you have time to think about it and discuss it your relatives and friends before you decide.

What is the goal of this project?
The goal of this research project is to analyze with infrared thermography the impact of piano practices on specific body regions that are put under stress when playing the piano (hands, wrists, arms, shoulders and elbows). Infrared thermography can detect very small variations of skin temperature, which may be the sign of inflammation or stress on neuromuscular tissues for the body regions mentioned previously.

This will help researchers to identify precisely which body areas are put under a lot of stress during regular piano practices and this could allow to develop new pedagogy techniques for the practice of the piano that minimize this stress.

What will happen to me if I decide to participate?
If you decide to participate in this research project, infrared thermal images of the hands, arms, and shoulders will be taken with an infrared camera as well as the activities of the arm muscles will be recorded using *electromyography.*

Preparation:
Since the skin surface temperature variations are extremely subtle and sensitive to environmental changes, we will ask you to conform to the following directives prior to the test session:

(a) No talcum powder, lotion, drug or deodorant should be used on the skin on the day of the session.
(b) No alcoholic beverages should be consumed 24h prior to the session.
(c) No hot beverages should be used at least 1 hour prior to the session.
(d) Avoid the use of procedure such as electromyography, acupuncture, myelography, transcutaneous electrical stimulation, hot or cold patches, or any other form of physiotherapy at least 24h prior to the session.
(e) Avoid prolonged sun exposure at least one week prior to the session.
(f) You should not smoke at least 2 hours prior to the session.
(g) You should not wear any ring, necklace, and bracelet during the session.
(h) You should not do any intense physical exercises at least 4 hours prior to the session.

Location:
The imaging session will take place in the music studio of the research laboratory in piano pedagogy in the department of music at the University of Ottawa.
Perez Hall, Room 204
50 University Street
Ottawa, ON K1N 6N5

Protocol:
The piano session will take approximately one and a half hours in total. It is advisable that the volunteer wears a regular T-shirt or blouse with short sleeves so we can take infrared (IR) thermal images of the following body parts: hands (palm and back), and the arms (back and front). The IR thermal images will be taken before, during and after the practice sessions.

The experimental steps are as follows:

(a) First, we will discuss the experiment. Then we would ask you to sign a consent form indicating that you agree to participate in the experiment and to fill out a questionnaire regarding your level of playing, number of years of playing, and which additional instruments you can play.
(b) Next, we would like you to sit comfortably for approximately 15 minutes. This step is necessary to allow your skin temperature to acclimatize to the ambient/room temperature. The first set of thermal images as will be taken.

- The next step involves you playing the piano for 10 minutes. The level of performance includes sight reading exercises – Grade 4 level. Immediately after you finish the 10 minutes performance, a second set of IR thermal images will be taken.
- Next, we would like you to play scales in sixteenth notes, four octaves at 112 beats per minute for 10 minutes, as follows:
  - Play all major scales, going up by half a tone (C, C#, D, E^b,...).
  - Play all minor scales, harmonic and melodic, going up by half a tone (C, C#, D, E^b, E,...). Again, a third set of IR thermal images will be taken.
  - Next, we would like you to play octave scales for five minutes or less if you become very tired. You should be following this pattern: Play all major scales, going up by half a tone (C, C#, D, E^b,...). A fourth set of IR thermal images will be taken. We would like to emphasise that you are free to stop playing the piano at any time if you feel tired or experience pain.

(c) Finally, you will stay for half an hour after the practice, during which we will collect two more sets of IR thermal images.

What are the potential risks or inconveniences?
There are no direct psychological or emotional inconveniences associated with this study. An infrared camera does not send any radiation and is non-invasive. The new laboratory environment, the duration of the session and the presence of researchers or students may be disorienting and you may lose your concentration. You will have the opportunity to get familiar with the equipment and the studio of the research laboratory before the sessions. In addition, the studio of the research laboratory was designed to recreate a natural familiar environment for children and students and looks very much like a classical music studio.

What are the advantages for me and others, if I choose to participate?
You will not receive any direct advantages from this project. However, this study will allow finding which body areas are under a lot of stress and/or inflammation during and after regular piano practices. This could lead to the development of pedagogical piano techniques that minimize these stresses.
Playing-relating disorders affect between 43% and 60% of musicians according to experts. Being able to understand the origin and the mechanism behind those disorders could help improving pedagogical strategies, and reduce the incidence of such disorders down to an acceptable level. In particular, this study could show that playing-related disorders occur from a young age.

How much will it cost?
It won't cost you anything. Participation in this project is absolutely free and on a voluntary basis.

Will I be paid?
No. You won't receive any financial compensation.

How will the anonymity and the confidentiality of my data be protected?

The identity of participants to this research project will be confidential. The results, including laboratory data and any other research data, could be published for scientific purposes but no mention of the name or any other means to identify your child will be made.
Each participant will receive an identification number. This number only and the following information will be made available to the researchers:

(a) Dates of imaging sessions
(b) Name and location of laboratory
(c) Age
(d) Gender
(e) Camera settings
(f) Thermal images
(g) Relevant comments

The correspondence between identification numbers and names of the participants will be kept in a separate database and only available to one of the main investigators. It will be destroyed at the end of the project.

The anonymous data collected will be kept for 5 years after the results have been published. The data will be stored on cd-roms and on a computer with restrictive access. Only the main investigators will have access to those data.

How can I cancel my participation to this project?
If you don't wish to participate in this research project anymore, for whatever reasons, please contact Safaa Mohamed at (613) 520 2600 extension 5586 or by email at safaamoh@sce.carleton.ca. You are free to withdraw your consent and to withdraw from the study at any time. During the duration of this research project, the researchers will mention to you any new or additional information that could change your decision to participate.

Your participation to this project can be terminated at the main investigator's request at any time if:

(a) You did not follow the directives
(b) The supervisor decides to end this project or
(c) For administrative reasons

Will I have access to recorded data? Will I be informed of the results of the project?
You will have access to your data. The results may be presented at conferences and published in relevant journals.
Who should I contact if I have any question?
Safaa Mohamed
Phone (office): (613) 520 2600 ext. 5586
Phone (cell): (613) 513-3936
Email: safaamoh@sce.carleton.ca
If you have any questions concerning your rights as a participant in a research project, you can contact:

Protocol Officer for Ethics in Research, Tabaret Hall, 550 Cumberland street, room 159, Ottawa, ON K1N 6N5, Ph.: 613-562-5841, email: ethics@uottawa.ca

A.2 Consent form

Research project title:	**Prospective study of playing-related musculoskeletal disorders linked to the regular practice of the piano, with infrared thermography.**
Name of researcher:	Safaa Mohamed
Institution, Faculty, Department:	Carleton University, Faculty of Engineering, Department of Systems and Computer Engineering.
Phone number:	613 520 2600 ext. 5586
Email address:	safaamoh@sce.carleton.ca
Name of researcher:	Dr. Monique Frize
Institution, Faculty, Department:	University of Ottawa, Faculty of Engineering, School of Information Technology and Engineering
Phone number:	613 562 5800 ext. 6065
Email address:	frize@genie.uottawa.ca
Name of researcher:	Dr. Gilles Comeau
Institution, Faculty, Department:	University of Ottawa, Faculty of Arts, Music School
Phone number:	613 562 5800 ext. 3483
Email address:	gcomeau@uottawa.ca

I, ______________________________, accept to participate in this research project led by Safaa Mohamed from the department of systems and computer engineering at Carleton University, Monique Frize from the department of systems and computer engineering at Carleton University, and Gilles Comeau from the Department of Music at the University of Ottawa. The goal of this research is to analyze the impact that piano practices have on various body regions (hands, wrists, arms, shoulders and elbows) with infrared thermography.

My participation's will consist essentially of attending one session that will last for one and a half hours. During the session, infrared images of my hands, arms, shoulders and elbows will be taken before, during, and after playing the piano. I will have to remove the clothes covering the body regions to be imaged for the duration of the session and 15 minutes before the practice. A sleeveless shirt may be worn. The sessions have been scheduled from to . The infrared images recorded as well as the age, gender and comments will be kept in a database. The content of the database will be used for the sole purpose of the research project described in the first paragraph by the researchers and my confidentiality will be respected.

I will have to play the piano in a room I am not used to, and I will have to play in front of other persons. I will be able to see the studio and the infrared camera before the session so that I feel comfortable with the room and the equipment.

I am free to refuse to participate. If I choose to participate, I am free to withdraw from the project at any time for any reason. If I choose to withdraw, the data gathered from me will not be used and will be destroyed.

The researcher has assured me that the data gathered from me will remain confidential and that my name and personal information will not be shared with other persons. The only people who have access to my data are the researcher and his three supervisors. I will not be identified in any reports or publications. The data will be kept on a computer for 5 years after the publication of the research results and will then be destroyed.

Any information about my rights as a research participant may be addressed to the **Protocol** Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, room 159, Ottawa, ON K1N 6N5, Ph.: 613-562-5841, email: ethics@uottawa.ca .

There are two copies of the consent form, one of which I may keep.
If I have any questions about the conduct of this research project, I may contact the researcher or his supervisors at the numbers mentioned above.

Research participant's signature: Date:

Researcher's signature: Date:

A.3 Questionnaire

ID number: Age: Gender:

(a) What is your current occupation?

(b) If a student, what degree program are you currently enrolled in and what year?

(c) If you are an employee, what is your current job?

(d) Are/ were you enrolled in a music program (for example, a conservatory or a university program)?
If yes, what year?

If not, what is the last level of music program you were in?

(e) Are you currently in a performance?

(f) How many years have you been playing the piano?

(g) How many hours (or minutes) of piano do you play every day?

(h) If you stopped playing the piano, then when was the last time you played?

(i) Do (or did) you play another instrument? If yes, please specify which instrument you have (or had) been playing and for how many years.

(j) Are you right handed or left handed?

(k) Do you have any of the following health problems? Please circle yes or no.

- Joint pain, swelling, erythema
- Muscular pain, swelling
- Bone and joint deformities or infections
- Metabolic bone disease
- Compartment syndrome
- Avascular necrosis
- Osteoporosis
- arthritis
- Other health problems that would affect the musculoskeletal system

Yes No

(l) Did you have an accident resulting in an injury (e.g. broken arm) within the last 12 months? Please circle yes or no.

Yes No

(m) Do you do a musical warm-up (e.g. playing slow scales or else)?

Yes No

a. If yes, what do you play?

(n) Do you do a physical warm-up before playing (e.g. stretching exercises, etc.)? Please circle one answer.

Never Sometimes Often Always

a. If yes, what warm up exercises do you do?

(o) Are there any other physical parameters that, according to you, influence the way you play the piano? If yes, please mention which ones.

(p) Do you have pain, weakness, lack of control, numbness, tingling, or other symptoms that interfere with your ability to play the piano at the level you are accustomed to?

a. If yes, where do you experience pain?

(q) How frequently do you experience these symptoms (pain, weakness, lack of control, numbness, tingling)? Please circle one answer.

Once in a while regularly constantly other:

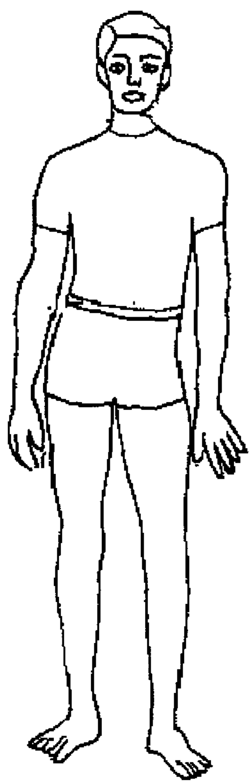
(r) If you experience pain, on a scale from 1 to 10, where 1 is very weak and 10 is very strong, how would you rate your pain?

(s) Are the symptoms controllable? Please circle yes or no.

Yes No

Other relevant comments:

If you experience pain, can you please indicate where on the following body diagram:



Appendix B

Code listings

This appendix contains the code that was used for analyzing the images, testing the data for normality, and calculating the statistical difference between the participants with pain related to piano-playing and participants without pain related to piano-playing.

B.1 Calculating the mean temperature for the regions of interest

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%This program takes a file that has the images to be analyzed and calculate

%the statistics for the region of interest that the user has selected

%June 2009

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

close all;
clear all;
%---read images from the database--------------------------
imagesfolder = dir('D:\MATLAB\pianodatabase\SafaaParticipants\.....\Left\LHD\*.MAT');
thr=24.0+273.15;      %set the threshold for isolating the background
n=length(imagesfolder);       %get the length of the folder that contains the images
newseq=true;  %said the flag to be true
SEQ_INDEX=1;       %set an index that marks the start of the sequence
ROIS_index=1;      %set an index that marks the start of the pixels count within the ROI
old_time=0;  %the previous sequence time
current_time=0;       %set the current sequence time
time_diff=0;          %the time difference between the old and the current %current is zero
%----------sort the images by time----------------------------------------
for I=1:length(imagesfolder);
        filenameI = imagesfolder(I).name; % get the file name
        [pathstrI, nameI, extI, versnI] = fileparts(filenameI);
        [E1,temp1,time]=filetogray(nameI);
```

```
        time_seconds=time(4)*60*60+time(5)*60;
         numstring=num2str(time_seconds);
         timename=strcat(numstring,nameI);
         c(I,1)={timename};
end
c=sort(c);%sorted
[mc,nc]=size(c);
for J=1:mc
%----------separate the filename from the time-----------------------
        [Time1,name_file]= strtok(c(J),'D');
         F = char(name_file);
         T1=char(Time1);
          T1=str2num(T1);
            [original,temp1,time]=filetogray(F);
            E1=original;%grey scale image (values between 0 and 1)
        if J==1
             old_time=T1;
         end
figure(1), imshow (original);
title(F)
%-----------the new sequence flag------------------------------------
while(newseq==true)
%------select the ROI---------------------------------------------
namemaskP=strcat(F,'LHD');
h=impoly;
BW= createMask(h);
imwrite(BW,namemaskP,'bmp');%save the mask
%BW=imread(namemaskP,'bmp');%read the mask (binary image)
c(J,3)={namemaskP};
newseq=false;
%ROIS_index=1;
 end
%------------Isolate the background---------------------------------
[M,N] = size(E1);
for i= 1 : M
        for j=1 :N
                if (temp1(i,j)>=thr) % foreground
                     E1(i,j)=1;
                else
                     E1(i,j)=0;
                end
              end
          end

          level = graythresh(E1);
```

```
    BW11 = im2bw(E1,level);
    E1=BW11;
    figure(2),h_im=imshow(E1);
    title('The image after isolating the background')


%------------get the region of interest------------------------------

   ROItoshow=immultiply(original,BW);

   ROI = immultiply(E1,BW);
   figure(3),imshow( ROI);
   ROIname=strcat(F,'ROI');
   title(ROIname)


%---------- create the ROI matrix-------------------------------------

   ROI_check=sum(sum(ROI));

   if (ROI_check~=0)% make sure it is not an empty frame
   [Mroi,Nroi] = size(ROI);


  for i= 1 : Mroi
    for j= 1 :Nroi
       if (ROI(i,j)==1)
          ROI_seq(ROIS_index,1)=temp1(i,j)-273.15;
          ROIS_index= ROIS_index+1;
       end
    end
   end
   end

%------------sequence calcualtions------------------------------------
  if (J+1<=mc)
    [Time2,name_file2]= strtok(c(J+1),'D');
    T2=char(Time2);
    T2=str2num(T2);
    current_time=T2;
    T_diff=T2-T1;

  end

  if(T_diff<=60)
```

```
            newseq=false;
          else

            newseq=true;  %new seq
          end

 %------- calculations of the sequence statistics------------------------
          if (newseq==true || J==mc)
              seq_time(SEQ_INDEX,1)=time_diff/60;
              seq_mean(SEQ_INDEX,1)=mean(ROI_seq);
              seq_max(SEQ_INDEX,1)=max(ROI_seq);%store the max temp for this seq
              seq_min(SEQ_INDEX,1)=min(ROI_seq);%store the min temp for this seq
              seq_diff(SEQ_INDEX,1)=max(ROI_seq)-min(ROI_seq);
              seq_std(SEQ_INDEX,1)=std(ROI_seq);
              seq_mode(SEQ_INDEX,1)=mode(ROI_seq);
              seq_median(SEQ_INDEX,1)=median(ROI_seq);
              seq_variance(SEQ_INDEX,1)=var(ROI_seq);
              seq_skewness(SEQ_INDEX,1)=skewness(ROI_seq);
              seq_kurtosis(SEQ_INDEX,1)=kurtosis(ROI_seq);

              SEQ_INDEX=SEQ_INDEX+1;
              time_diff=time_diff+current_time-old_time;
              old_time=current_time;
                  x = 23:1:35;
              figure(8), hist(ROI_seq);
              xlabel('Temperature in Celsius')
              ylabel('Number of pixels')
             pause (3)
              clear ROI_seq
              ROIS_index=1;
         end

end

%---------------write the data to an excel file----------------------------
SUCCESS = xlswrite('D:\matlab\data.xls', seq_time,'data','A4')
SUCCESS =xlswrite('D:\matlab\data.xls',seq_mean,'data','B4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_max,'data','C4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_min,'data','D4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_diff,'data','E4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_std,'data','F4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_variance,'data','G4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_mode,'data','H4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_median,'data','I4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_skewness,'data','J4')
SUCCESS = xlswrite('D:\matlab\data.xls',seq_kurtosis,'data','K4')
```

B.2 Lilliefors test

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%This program tests the data for normality

%we combined the temperatures measurements

%and used the function Lillietest to test the data for normality

%August 2010

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

close all;
clear all;
x=[
        %P14
         30.51426758;31.28617949;30.09495901;29.85024744;
         31.7639064;31.4721505;31.24785872;30.66559993;
         32.3393401;30.49517652;31.86017627;29.51401641;

         %P16
         30.3329043;29.04592034;30.60976628;28.35314266;
         30.10567806;30.16053084;30.2257749;29.7199176;
         31.06926503;29.24695079;31.40498709;29.35821011;

         % P17
         32.04445896;31.86835585;32.96007717;29.33541904;
         31.69068382;31.67628517;32.46449821;31.4913318;
         32.08368765;31.79255144;32.73763516;30.99785495;

         %P18
         32.89465151;31.87152865;30.18628493;30.74819795;%hand temperatures
         31.7023436;31.26281054;30.95594003;30.03548796;%lower arm temperatures
         31.54063046;30.79026306;31.17610466;29.52104636%upper arm temperatures
         ];

[H,P,KSTAT,CRITVAL]=lillietest(x,0.05,'norm',1e-2)
```

B.3 ANOVA test

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        %This program performs ANOVA test for normality on the hand temperatures

        %before the participants started playing the piano and after the 15 minutes

        %of temperature stabilization

        %August 2010

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

close all;
clear all;

%--------The hands temperature at the beginning of the session--------

%---The normal /control subjects---

P14=[30.51426758;31.28617949;30.09495901;29.85024744];
P16=[30.3329043;29.04592034;30.60976628;28.35314266];
P17=[32.04445896;31.86835585;32.96007717;29.33541904];
%----The Abnormal subjects---

P18=[32.89465151;31.87152865;30.18628493;30.74819795];
P12= [34.02203083;32.76878028;34.72552748;33.20763187];
P13=[32.34376383;31.41636322;32.29272997;31.80029816];
P15=[34.53488945;33.52797762;34.18088689;33.35316184];
P19=[33.58841829;32.14068787;32.92072878;31.64554726];
P20=[33.28294414;32.65072304;32.89975918;32.96720241];

N=[P14;P16;P17];%the normal group
A=[P18;P12;P13;P15;P19;P20];%the abnormal group
%--create the matrix--
xx=nan(length(A),2);
 xx(1:length(N),1)=N;
xx(1:length(A),2)=A;
group={'pianists without pain','pianists with pain'};
 %--run anova test--
p = anova1(xx, group)
ylabel('Temperature in Celsius')
```

Appendix C

C.1 Temperature over time plots for individuals

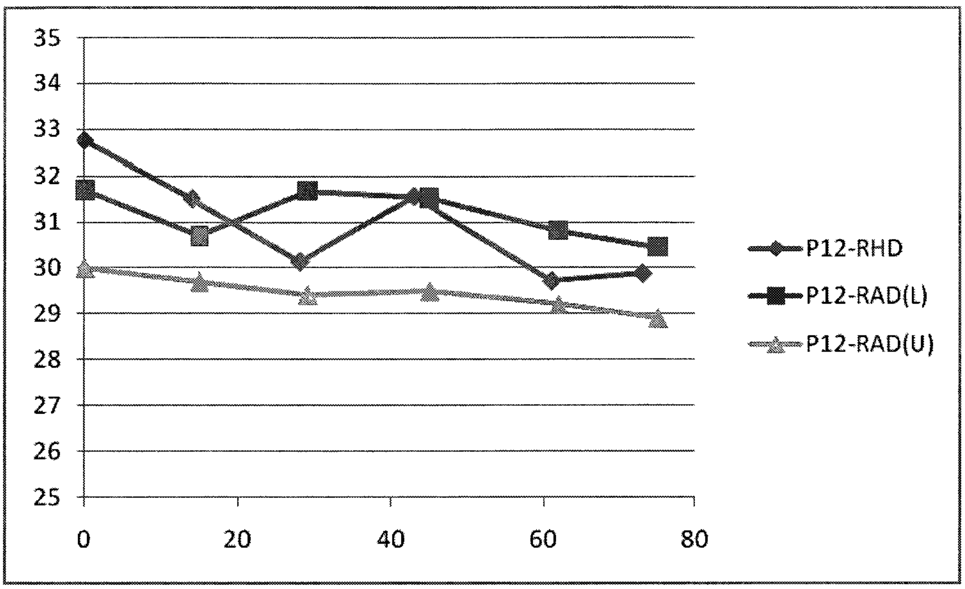


Figure C.1: Temperature over time plot for the right upper extremity for participant P12 (pianist with pain). The hand temperature is higher than the arm temperature.

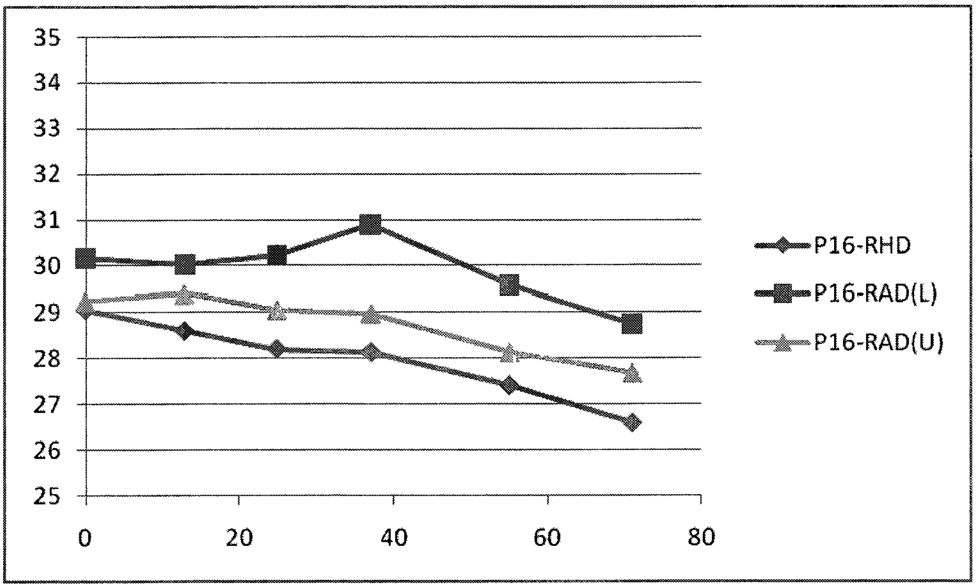


Figure C.2: Temperature over time plot for the right upper extremity for participant P16 (pianist without pain). The hand temperature is lower than the arm temperature.

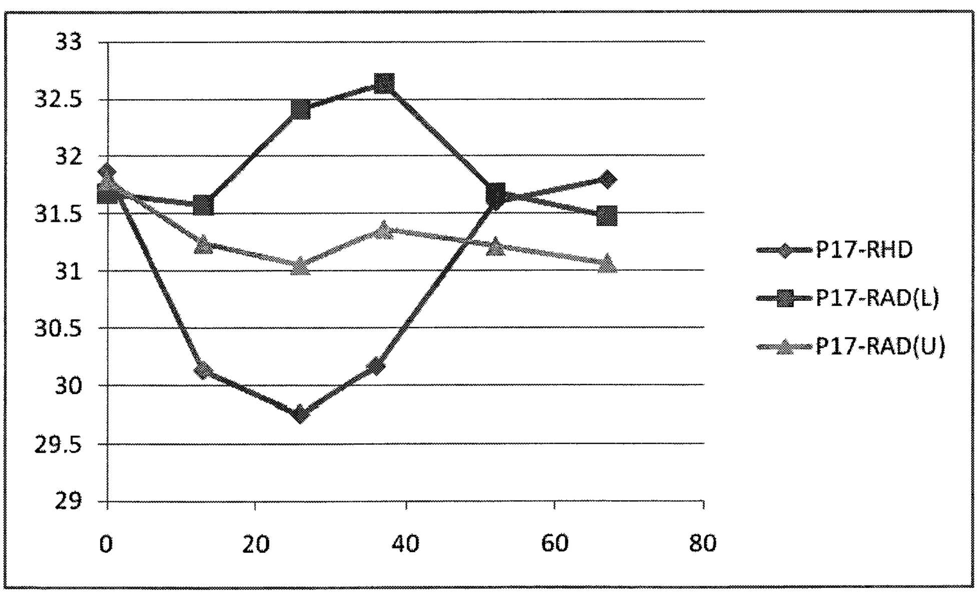


Figure C.3: Temperature over time plot for the right upper extremity for participant P17. The hand temperature is lower than the arm temperature.

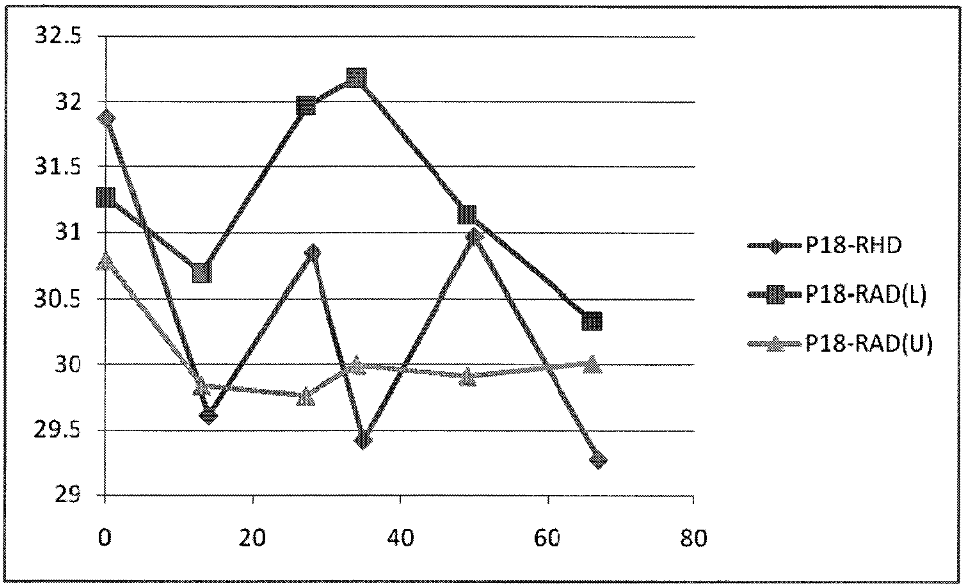


Figure C.4: Temperature over time plot for the right upper extremity for participant P18, who has pain after playing the piano for a long time.

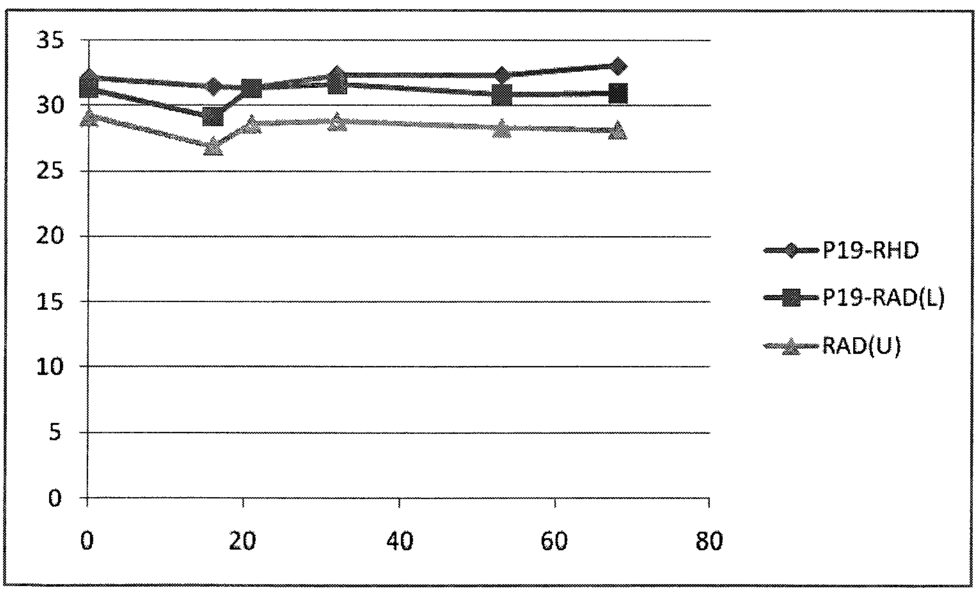


Figure C.5: Temperature over time plot for the right upper extremity for participant P19 (pianist with pain).

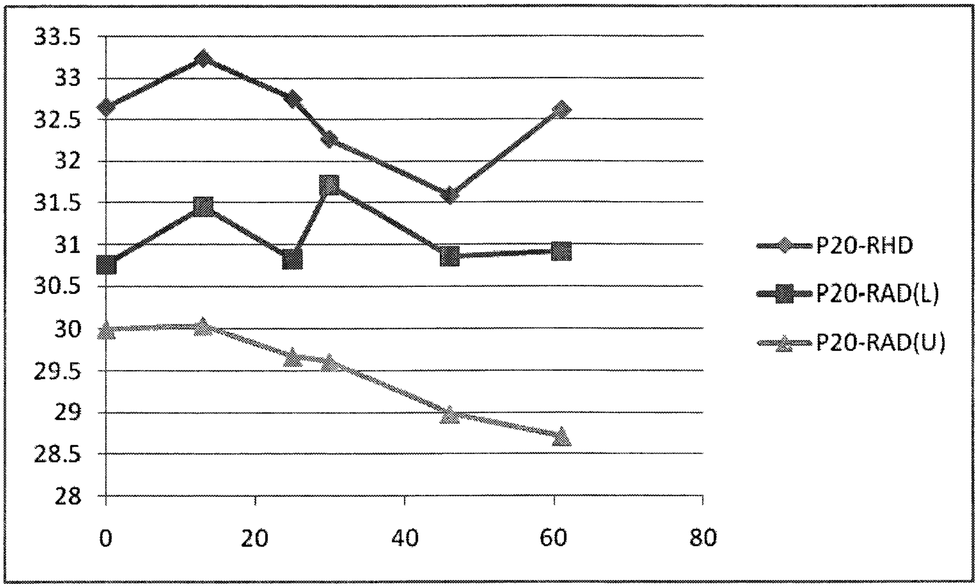
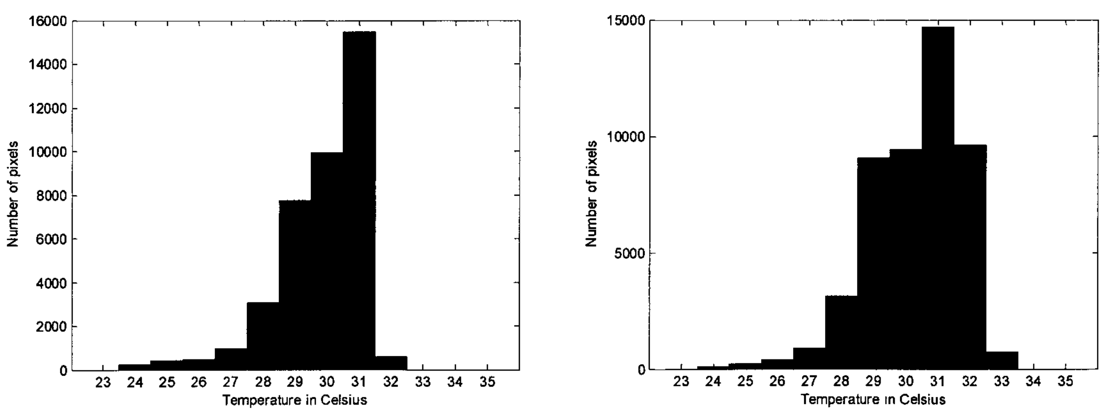


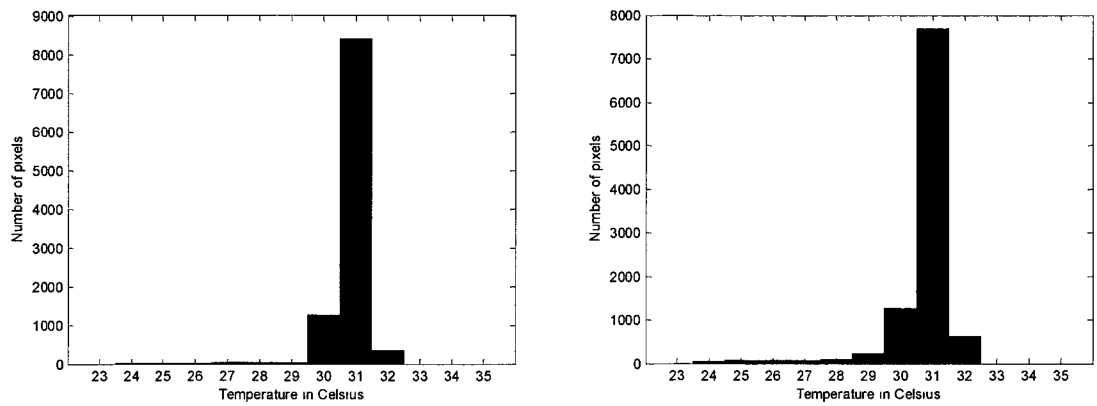
Figure C.6: Temperature over time plot for the right upper extremity for participant P20, who has a musculoskeletal disorder.

C.1 Histogram plots



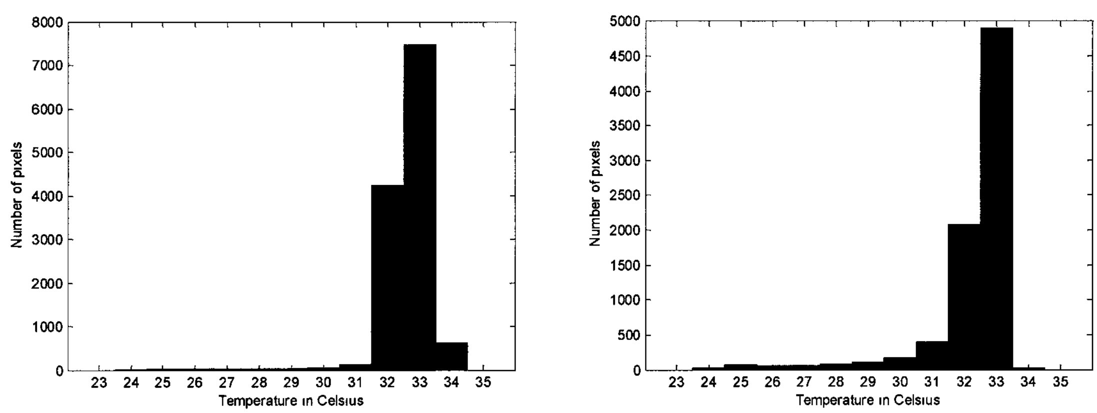
(a) (b)

Figure C.7: Histogram for participant P12 (pianist with pain), (a) right hand dorsal, and (b) left hand dorsal.



(a) (b)

Figure C.8: Histogram for participant P13 (pianist with pain), (a) right hand dorsal, and (b) left hand dorsal.



(a) (b)

Figure C.9: Histogram for participant P20 (pianist with pain), (a) right hand dorsal, and (b) left hand dorsal.