33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Assessment of Piano-Related Injuries using Infrared Imaging

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Abstract— **Playing the piano is a repetitive task that involves the use of the hands and the arms. Pain related to piano-playing can result in 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 a sign of inflammation or stress of the tissues. In this paper, we used statistical analysis to examine the difference in hand and arm temperatures of pianists with pain and pianists without pain related to piano-playing. We found that there is a statistically significant difference in hand temperatures between the two populations, but not in the lower arm and upper arm temperatures.**

I. Introduction

PLAYING the piano is a complex skill that requires hours of practicing, and involves a broad range of movements, from pressing down the keys to play a simple scale, to using the whole body in playing arpeggios and chords. It is easy to build up muscle tension during piano-playing while focusing on achieving the right sound and notes [1]. Piano-playing related injuries, known as overuse syndrome, are a type of musculoskeletal disorder caused by repeating certain movements, which can result in trauma to the muscles and the joints and can affect the hand, wrist and elbow [2],[3].

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 [4]. A second study was conducted with 59 questionnaires for musicians who played a variety of instruments, including the flute, trumpet, and piano. The study found that 70% of the participants have or have 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 [2].

Practicing with the wrong technique over and over again can result in hot and inflamed muscles. Infrared imaging is a useful way to study heat associated with overworked muscles because it measures the body's temperature accurately, as it does not produce any ionizing radiation and does not touch the subject during the measurements [5],[6].

Manuscript received April 15, 2011. This work was supported in part by the Natural Sciences and Engineering Research Council of Canada.

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Skin temperature is affected by blood perfusion; therefore diseases that affect blood circulation, especially in the extremities, can be studied using infrared imaging. Abnormalities such as inflammation or malignancies result in increased tissue temperature which would show either as a hot area or as a non-homogeneous area in the thermal image. Thus, infrared imaging is a good tool to study diseases such as breast cancer, arthritis, and pain [7].

Infrared imaging has no known risks associated with it which makes it a good choice for a long term study of inflammatory diseases or pain [8],[9]. In 2005, Herry et al. used infrared imaging to study the temperature of arm muscles during and after piano-playing [10],[11]. A new study in 2010 by the authors of this paper recruited nine subjects, some with pain and others without pain related to piano-playing. The objective of the new study was to see if there is a correlation between heat and pain as a result of repetitive strain injuries.

II. Methodology

A. Data Acquisition

There were nine participants in our study, with ages ranging from 20 to 65 years old, who 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 to piano-playing nor did they have any musculoskeletal disorder that affected their muscles or joints. Six of the participants suffered from pain that they related to piano-playing. Out of the six participants with pain, four had pain while playing the piano at the time of the experiment.

The study was cleared by the ethics committee at the University of Ottawa. The number of participants in our preliminary study was not very large because the participants had to have certain characteristics to qualify for our study: all participants had to be at least intermediate level at playing the piano, if they suffer from pain then the pain must be the result of piano playing, and they must play the piano regularly. In addition, the experiment was an hour long and was absolutely on a volunteer basis with no direct reward to the volunteers.

Participants were advised to wear sleeveless shirts to expose the hands, the arms, and the shoulders to the infrared camera. Since infrared imaging records the skin temperature, which can be affected by several factors, the participants were asked to follow certain preparation guidelines: refrain from drinking alcohol 24 hours prior to the experiment and drinking hot beverages at least 1 hour prior to the experiment; avoid smoking two hours before; avoid long exposure to sunlight and tanning beds one week before; avoid the use of talcum powder, lotion, deodorant, perfume and wearing rings or jewelries on the day of the experiment; avoid physical exercises at least 4 hours prior; and avoid the use of procedures such as electromyography, acupuncture, hot or cold patches, or any other form of physiotherapy for at least 24 hours prior to the session. The room temperature was kept at 20° Celsius for all the imaging sessions. The participants were instructed to play specific piano exercises. The first activity was slow and technically easy, the second set of exercises was of medium difficulty, and the last set was 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. Images were taken by a FLIR 320M infrared camera, which was connected to a laptop. The first set of images was taken after the fifteen minutes of body temperature stabilization; then the participants were instructed to play the piano as follows:

- First, to play the piano for 10 minutes. The level of performance included sight reading exercises at the grade 4 level; a second set of IR thermal images was taken immediately after finishing the 10 minute exercise.
- Then, 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, then play all minor scales (C, C#, D, E^b, E, etc.), harmonic and melodic, going up by half a tone. A third set of IR thermal images was taken immediately after the participants stopped playing this second set of exercises.
- Finally, to play octave scales for five minutes or less if they become very tired. They were instructed to play all major scales (C, C#, D, E^b, etc.) going up by half a tone. A fourth set of IR thermal images was taken immediately after they stopped playing.

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. Images of the participants were taken at a distance of one meter to two meters and they were asked to stand up while being imaged. Images of the hands dorsal (back) and palmar (front) and arms interior and posterior were collected each time.

B. Data Processing

The first step before analyzing the images involved removing the background from the region of interest; this is a challenging problem in infrared images because the background temperatures can overlap with the temperatures in the regions of interest. Several segmentation techniques have been proposed in the infrared imaging literature [11]; however, segmentation remains a challenging problem in image processing. In this pilot project, we segmented our images by thresholding with a manually chosen threshold, with the intent of automating the process in future work. We initially chose the threshold to be 23° Celsius, but found that values at 23° Celsius or below introduced noise and unwanted details in our images. So we proceeded to increase the threshold by 0.1° Celsius until we obtained a clear segmentation, that is, the background was removed. We found that a value of 24° Celsius (297 Kelvin) was successful in isolating the hand and the arm regions from the background for most of the images. For a few of the images, we obtained better results with a threshold of 23.8° Celsius. A value of 1 was given to pixels greater than or equal to the threshold value, otherwise a value of zero was assigned to the pixel. The second step in processing the images involved selecting the region of interest to be analyzed in the image. This selection was done manually by placing a polygon around the area of interest on the front and back view of the hands and of the arms. For the hands, we chose to focus on the palms because the fingers of the hands for some players were coming colder than the room temperature during piano-playing. The resulting images are shown in Fig. 1.

Fig. 1. Selecting the regions of interest (a) the hand (b) the lower arm and (c) the upper arm.

III. Results

A. Testing Data for Normality

First, we tested our data for normality to determine which statistical test should be used to differentiate between the group who had pain related to piano-playing and the group who did not have pain related to piano-playing. Lilliefors is a two-sided goodness-of-fit test that is used to determine if the data came from a normal distribution or not. This test takes input data in vector x and 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.

In our case, vector x contained the mean temperature values at time t=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 regions of interest for the left arm). The test returned h=0, indicating that the data had a normal distribution.

B. Statistical Analysis

Since our data was normally distributed, we chose the ANOVA test which compares the mean of two or more groups to see if they have equal means. The ANOVA test takes two different distributions, where each distribution represents a set of independent samples that contain mutually independent observations. The test returns a value called p; if p is close to zero, then at least one sample mean is different from the other sample mean. Here, the first distribution contained the mean temperature measurements for each part of the hand and arm at a specific time for the pianists without pain; the second distribution contained similar data for the pianists with pain. We tested our data at a significance level of 0.05 (95% confidence level). The ANOVA test produces a box plot for each column in the matrix X representing 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 inter-quartile range far from the top or the bottom of the box. Whiskers are drawn from the end of the inter-quartile ranges to the furthest observation within the length of the whiskers. A non centered median line indicates sample skewness. 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. We ran the ANOVA test for the hand, the lower arm and the upper arm mean temperatures for each stage of the experiment.

First, 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 the participants started playing the piano. The ANOVA test returned $p=7.95\times10^{-6}$. This value being close to zero, we conclude that the means of the two groups were significantly different. The box plot for the test results is shown in Fig. 2.

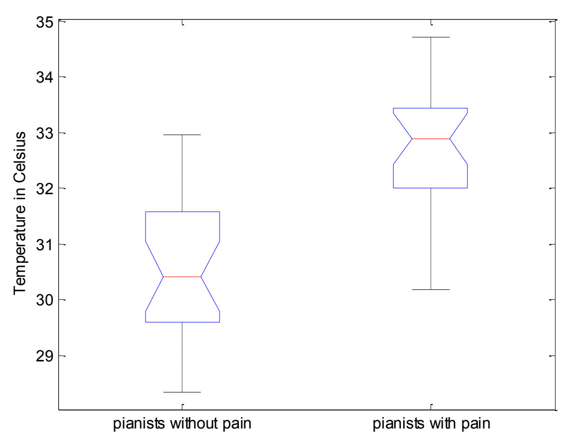

Fig. 2. ANOVA test box plot for the hand mean temperature measurements at time t=0.

Next, we ran the same test for the mean temperature measurements for the lower arms at t=0 to see if the two groups were different. The test returned p = 0.89; this shows that the test could not establish that the two groups were different. Then we ran the test at time t=0, for the upper arm mean temperature measurements. The test returned p=0.07, which is 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. We also ran the ANOVA test on the temperature measurements for the lower and upper arms combined and we received p=0.22, which shows that the test could not differentiate the two groups based on the arm temperature measurements.

Next, we ran the ANOVA test for the temperature measurements for the hands at time t=1 after the participants had finished playing the first piano exercise. The test returned $p=5.22\times10^{-7}$, indicating that the correlation between heat and pain can be seen based on the hand temperature measurements. The box plot in Fig. 3 shows that the two groups can be distinguished from each other based on their hand temperatures.

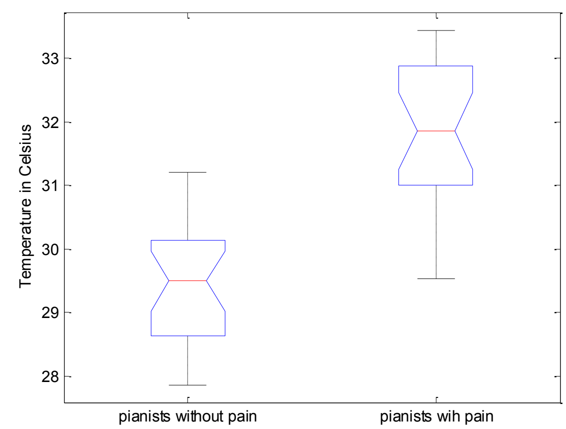

Fig. 3. ANOVA test box plot for the hand mean temperature measurements at time t=1.

Next, we ran the ANOVA test for the mean temperature measurements for the hands at time t=2 after the participants had finished playing the second set of piano exercises. The test returned $p=5.24\times10^{-7}$, 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 Fig. 4.

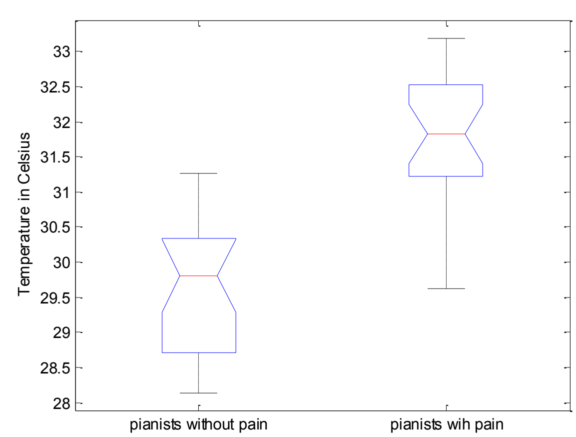

Fig. 4. ANOVA test box plot for the hand mean temperature measurements at time t=2.

Then, we ran the ANOVA test for the mean hand temperature measurements at time t=3 after participants had finished playing the last set of piano exercises. The test returned $p=3.52\times10^{-5}$, indicating that the means for the two groups were significantly different. The third set of piano exercises was 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 without pain. However, pianists with pain exhibited higher temperature overall, as shown in the box plot in Fig. 5; the "+" sign shows that there were outliers, possibly those who did the third set of exercises only for a very short time or not at all.

We also ran the ANOVA test to see if we could differentiate the two groups statistically based on the lower arms' mean temperature measurements 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 mean temperature measurements.

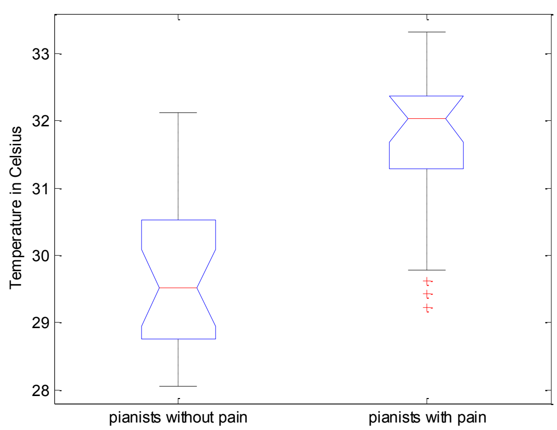

Fig. 5. ANOVA test box plot for the hand mean temperature measurements at time t=3. The "+" signs indicate outliers.

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 $p=6.95\times10^{-5}$, indicating that the two groups were statistically different.

IV. Conclusion

We found that there was a correlation between heat and pain due to piano playing which showed in the difference in the mean temperature of the hands between pianists with pain and pianists without pain. Pianists with pain were found to be statistically different from pianists without pain, based on the mean temperature measurements of the hands, even before they started playing the piano; this might be due to the permanent injuries to their tendons and ligaments that become aggravated upon playing the piano. Our statistical analysis for the lower and upper arm mean temperature measurements were not useful in differentiating the two groups.

As a first attempt to study the problem of pain in piano players, the data gathered was very useful to assess the experimental protocol created and to identify how to carry out a much larger study in the future. The research confirmed that our protocol and experimental design led to meaningful results and is a good template for further studies with piano players and other types of musicians in the future.

We also found that the hands are far more indicative of problems than the arms, which means that we could shorten the sessions by eliminating the measurements in the arms in future studies. 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. We can also speculate that some pianists push themselves really hard and might be at risk of developing pain related to piano-playing later in life. Infrared imaging would be a good way to detect these problems early on and prevent serious pain or injuries in the future. Future work will also develop a more automated method for removing the background information and to select the regions of interest.

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