Gait analysis of lumbar muscle activation patterns during constant speed locomotion using Surface Electromyography

A thesis submitted in fulfillment of the requirements for the degree of Master of Engineering

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed

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Date:
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Abstract

This thesis reports research on analysis of the variance of surface electromyogram (sEMG) for healthy participants and people suffering with Lower Back Pain (LBP) when they are walking and running. SEMG signal recorded when the participants were walking and running on a treadmill. The strength and duration of the muscle activity for each heel strike were the features.

The results indicate that there was no significant difference in the variance and in the change of variance over time of the amplitude between the two groups when the participants were walking. However when the participants were running, there was a significant difference in the two cohorts. While there was an increase in the total variance over the duration of the exercise for both the groups, the increase in variance of the LBP group was much greater (order of ten times) compared with the participants with healthy backs. The difference between the two groups was also very significant when observing the change of variance over the duration of the exercise. From these results, it is suggested that variance of sEMG of the muscles of the lower back, recorded when the participants are running, can be used to identify LBP patients.
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Acronyms

Computed Tomography (CT)
Chronic Low Back Pain (CLBP)
Clavicle Bone (CB)
Erector Spinae (ES)
Independent component analysis (ICA)
Low back pain (LBP)
Magnetic Resonance Imaging (MRI)
Multifidus (MF)
Muscle Activation Strategy (MAS)
Nucleus Pulposus (HNP)
Posterior superior iliac spine (PSIS)
Power spectral density (PSD)
Root Mean Square (RMS)
Straight leg raising (SLR)
Standard Deviation (STDEV)
Surface Electromyography (sEMG)
Transverses Abdominis (TrA)
Chapter 1: Introduction

Over 80% of the Australian adult populations are expected to experience Chronic Low Back Pain (CLBP) or LBP sometime in their life span (Denbigh P…1998). The situation in countries such as America, Japan and UK is similar. Today’s medical technology does not offer reliable non-invasive technique to identify CLBP or LBP. The reason that we need to have a technique to identify CLBP in earlier stage is to give the patient a better chance to fully recover without any long term treatment or surgery. It also helps the government and medical insurance companies to save their money. In 2005 WorkCover Victoria (Workcover Vic, 2005) reported; from 1985 to 2005 there were over 26% of all claims directly related to back injury or disease and $1.3 billion had been paid for back injury or disease. It has been reported that occurrence of CLBP can be predicted based on surface electromyography (sEMG) of the lumbar back (Moritani T et al & Nagata A et al…1986).

Chronic Low Back Pain is identified as pain between spine vertebra L1 to L5 when a person perform any daily routine such as walking, running, and any other body motions. Some researcher suggests that approximately 80% of all the back pain ailments are of unknown origin (Lutz V…2001). A general lack of knowledge exists concerning the etiology and specific symptoms related to nonspecific chronic low back pain (CLBP).

One of the techniques used to assess the occurrence of CLBP is based on gait analysis which requires the gait laboratory and the test is cumbersome. The other option is the use of MRI or ultrasonography to identify the health of the back muscles. There is need for a simple non-invasive gait analysis measure that can be effectively used for identifying any abnormalities. The activities of the associated lumbar musculature such as erector spinae (ES) and Posoas major muscle have proven to be useful in study of human gait (Crosbie J et al…1997).

Surface electromyography (sEMG) is a measure of the electrical activity associated with muscle contraction and has the advantage of being non-invasive, is easy to record and the equipment is economical and portable. Devices such as Myovision 2000 have attempted to use sEMG of the muscles of the back to identify Sublaxation and back ailments. Unfortunately sEMG is not very reliable when the muscle activity is small, and when there are multiple muscles that are simultaneously active in the region of the electrodes. There is also the shortcoming of there being large inter-subject and inter-experimental variations, making the analysis of the absolute values of the magnitude erroneous. Work by Kamai et al (Kamai, Kumar and Polus, 2007) has
Chapter 1: Introduction
demonstrated that sEMG of the muscles of the lumbar region during maintained posture is not reliable.

To overcome the above shortcomings of use of sEMG, this study reports analysis of the features of sEMG recorded during walking and has identified some of the features of sEMG that are reliable and directly related to the gait of the person. The study has experimentally identified the differences between people with healthy backs and people with CLBP. The results have been analysed to determine the variation in the recordings and impact of normalization. The change in the normal sEMG during ten minutes of walking and ten minutes of running under controlled conditions has been studied. The results indicate that while there is large inter-subject variation in the magnitude of the signal, sEMG is a good measure of the activation and deactivation of the muscles where the intra-subject variations are small. The results also indicate that the normalized magnitude of the signal is a reliable indicator of the strength of muscle contraction.

1.1: Research Objective

The research objectives of this research are given below:

1) Identify the dynamic pattern of sEMG of the lumbar region with different walking speed for people with healthy back people and with CLBP. The focus of this study was on lumbar muscle activation period and the change in amplitude during different walking speed for the two cohorts.

2) Compare the dynamic pattern between healthy subjects and low back ailment subjects, and identify any significant changes that differentiate between people with healthy backs and suffering from low back pain.

A successful study could result in an early diagnostic system that can be used to identify people with LBP in the early stages. Such a system would be sEMG based and thus would be inexpensive and non-invasive. The result of such a system will be to reduce the cost and suffering due to such ailment. This improvement has two social benefits; 1) Reduce and prevent the back ailment and thus improve the quality of life. 2) Reduce related expense and improve efficiency of the work force. Such a system would be suitable for use in hospitals, gyms, clinics and by manual therapists.
Chapter 1: Introduction

1.2: Thesis Outline

1) Chapter 1 is an introduction to the issues related to the research objective of developing a technique of identifying LBP patients based on sEMG. In this chapter, the thesis has also been introduced.

2) Chapter 2 provides the literature review related to sEMG and muscle activation pattern from different experimental conditions in healthy and LBP groups. The review includes developing the support of our hypothesis and explains the selection of the lumbar muscle that has been studied in this research.

3) Chapter 3 outlines the experimental setup and protocol. This includes the sEMG recording procedure and a summary of the initial condition of the participants.

4) Chapter 4 outlines the experiment methodology and data analysis technique.

5) Chapter 5 provides the results, observations and discussion of the experimental outcomes.

6) Chapter 6 concludes the thesis with a summary of result and observations, the outcomes of this study and recommendation for related future work.
Chapter 2 Literature Review

2.1: Introduction

The aim of this study was to determine the basis for non-invasive sEMG based diagnostic technique for differentiating the healthy back and low back ailments cohort. Towards this outcome, literature was reviewed to identify related work and determine the outcomes of the earlier research. The next section is a review of the anatomy of the spine and the current understanding of Low Back Pain (LBP). In the following section, the commonly used techniques used for LBP diagnosis and to determine the progress of the patient have been reviewed. The shortcomings of these techniques have been discussed and the current techniques that use EMG for LBP diagnosis have been provided.

2.2 Background Information

For better understanding of the problem, the fundament of anatomy of the human spine was studied from an engineering perspective.

2.2.1: Anatomy of Human Spine

Figure 2.1: Spinal Column (Eidelson S.G 2006, para 2)

- There are seven flexible cervical (neck) vertebrae that support the head.
- There are twelve thoracic (chest) vertebrae, which attach to ribs.

Lateral (Side) Spinal Column

Posterior (Back) Spinal Column

Cervical
Thoracic
Lumbar
Sacrum
Coccyx

Cervical
Thoracic
Lumbar
Sacrum
Coccyx
Chapter 2 Literature review

Human spine comprises 33 vertebrae (bones stacked on top of each other in a "building-block" fashion) that have 4 distinct regions: Cervical, Thoracic, Lumbar, and Sacral. Between each vertebra, there is an inter-vertebrae disc, acts as the spine's shock absorbing system. The spinal cord is housed within the protective spinal column. Spinal nerves come from the spinal cord and travel through a tunnel or foramen. The nerves provide sensory (allowing you to touch and feel) and motor information (allowing the muscles to function) to the entire body.

Figure 2.2: The Intervertebral Disc (Eidelson S.G 2006, para 5)

2.2.2: Low Back Pain and Chronic Low Back Pain

LBP is identified as pain between spine vertebrae L1 to L5 when a person performs any daily routine, such as walking, running, and any other body motions (Lutz Vogt, PhD, Klaus Pfeifer…2001).

Figure 2.3: The lower section of spinal column (Eidelson S.G 2006, para 2)

CLBP has been defined as pain lasting for more than 3 months in the area below the inferior border of the twelfth rib and above the gluteal folds.
Chapter 2 Literature review

2.2.3: Causes of Low Back Pain

There are many different causes of LBP, not all of which originate from your spine. The most common low back pain causes are Muscle Strains and Lumbar Sprains, Lumbar Radiculopathy, Herniated Disc and Degenerative Discs.

2.2.3a: Muscle Strains and Lumbar Sprains

A low back muscle strain occurs when the muscle fibers are abnormally stretched and injured. A lumbar sprain occurs when the ligaments and the tissues that connect bones together are torn from their attachments.

Figure 2.4: Spinal Ligaments (Eidelson S.G 2006, para 3)

2.2.3b: Lumbar Radiculopathy

Lumbar radiculopathy refers to the LBP caused by compression of the roots of the spinal nerves in the lumbar region of the spine. This type of LBP normally occurs in the lower extremities of the spine in a dermatomal pattern. It is caused by the lumbar disc bulges in stenotic canal, which compresses the nerve root and cause lumbar pain pattern, with pain radiating down to the foot. So this pain is similar to dermatomal nerve root compression.
2.2.3c: Herniated Disc

Herniated Disc is herniation of the nucleus pulposus (HNP), it occurs when the nucleus pulposus (gel-like substance) breaks through the annulus fibrosus (outer ring-like structure) of an intervertebral disc (spinal shock absorber). The nucleus pulposus does not have nerves, but the outer annulus fibrosus contains nerve fibers. When the disc cracks, the nucleus pulposus will leak and meet the annulus fibrosus and the annulae nerves. If this happens, a chemical called a proteoglycan may be released from the nucleus pulposus, irritate the annular nerves and cause an inflammatory response and pain. (Mummaneni P.V & Spinasa S….2006, para 1-5)

Figure 2.5: Anatomy of Herniated Disc (Mummaneni P.V & Spinasa S….2006, para 5)

A herniated disc occurs most often in the lumbar region of the spine especially at the L4-L5 and L5-S1 levels. This is because the lumbar spine carries most of the body's weight. People between the ages of 30 and 50 appear to be vulnerable because the elasticity and water content of the nucleus decreases with age. (Dawson E.G. 2006, para 1)

The progression to an actual Herniation of nucleus pulposus varies from slow to sudden onset of symptoms. There are four stages:

Figure 2.6: The four stage of Disc Herniation (Dawson E.G. 2006, para 3)
Chapter 2 Literature review

Stages 1 and 2 are referred to as incomplete, where 3 and 4 are complete herniations.

2.2.3d: **Degeneration Discs**

As mentioned before, the discs help to absorb pressure and keep the vertebrae from grinding against each other (Eidelson S.G 2006, para 2). Disc degenerates when we age, it becomes less elastic and will lose its ability to hold water, resulting in decreased ability to absorb shock and a narrowing of the nerve openings in the sides of the spine, which may pinch the nerves and cause pain. (Amundson G.M, 2006 para 1-2).

2.2.4: **Diagnostic Tools for LBP**

2.2.4a: **X-Ray**

X-Ray of spine shows the bony anatomy, the doctor/physician can diagnose the cause of LBP by checking the alignment and integrity of the bony structure. X-Rays makes use of electromagnetic radiations to show your bones and joints, it shows whether there is any degenerated condition like osteoporosis or whether there is any bones dislocated or broken. However it failed to show problems of your spinal cord, fibrous tissues, muscles, nerves or discs. X-Ray for disc normally requires injection of a special dye into discs that are suspected to be the source of pain. This is a painful test, so it has been replaced by MRI and CT scan. (backpaindetail….2008, para 3)

2.2.4b: **Computed Tomography (CT) scans**

It uses a beam of special X-rays to rotate around the affected area, produces a 3-D image of a section of the body and shows the cross section image of spines. It is able to capture detailed bone image, however, it is not that good in showing soft tissues like nerves, tumors and herniated discs. (backpaindetail….2008, para 5)

2.2.4c: **Magnetic Resonance Imaging (MRI) Scans**

MRI is sensitive to hydrate, so that it can produce clear image of the bone and soft tissue of the spine. In this image, the doctor/physician can see the soft tissue structure such as disc, ligament, spinal cord and spinal nerves. It can help them to identify any Disc Degeneration, Bulging or Herniation. However, using MRI to
determine treatment may cause unnecessary surgeries, as many people have no low back pain whilst having protruding vertebral discs. It is expensive and less effective in identifying bone problems compared with X-Ray.

**Figure 2.7: The X-Ray and MRI images for a patient who suffer from herniated disc (Skleton A…2006, para 2-4)**

2.2.4d: Nerve root tension tests

It is used to confirm the presence of sciatica by attempting to reproduce the discomfort with certain motions and body positions. These tests are performed by a doctor and involve moving the legs in certain ways that slightly stretch the sciatic nerve. If the patient experiences pain during these tests, an irritated sciatic nerve is likely to be a source of the pain. However, the accuracy of cause is low, as it is not able to show Disc Degeneration, Herniation or other causes. (Skleton A…2006, para 2-4)
2.3: **EMG of the Back Maintained Posture**

The first set of related studies is based on a commercially available system and related papers. Myo Vison 2000 have developed a system that studies in real time the sEMG of the back muscles ([www.myovision.com](http://www.myovision.com)) and appear to have sponsored or supported number of studies related to low back pain diagnostics and EMG. The system supplied by them appears to be targeted for chiropractors and physiotherapists, and appears to require very little preparation by the user. The system records an imbalance in the sEMG from the two sides and uses this information to display such imbalances.

Studies conducted by Ambroz et al (Ambroz A et al, 2000) suggest that use of sEMG is suitable for identifying LBP. Their study supports the use of EMG during maintained posture and concludes that this provides useful information for the clinicians to identify the location of the muscle weakness and also for diagnostic purposes for people with LBP. Later review by the same authors concluded that while use of sEMG was controversial, they reviewed 44 scientific papers and concluded that sEMG was extremely useful for identifying people with LBP and for determining the progress of treatments. Other related works by these authors include determining the difference between the standing and sitting EMG.

Djuwari et al and Naik et al have found that there are number of artifacts in the EMG signal through different experimental studies. The most commonly found artifact is ECG which in these studies appears to be greater intensity compared with EMG and this makes EMG highly unreliable. These studies concluded that there was need for undertaking source separation to improve the signal to noise ratio and thus make the experiments more reliable. These studies recommended the use of ICA for reducing the artifacts and improving the quality of the signal.

Similar studies have been reported by Hu (Hu et al, 2005, 2007). These studies also found that there was a need for processing the sEMG prior to using it to identify the issues related to the muscles of the lower back. These researchers also recommended the use of ICA to separate the artifacts.

The studies done by Kamai et al (Kamai, Kumar and Polus, 2007) indicate that even though there is a strong argument for using sEMG of the back for a number of applications, including the posture studies and the low back ailments studies, the reliability of such recordings is extremely poor. These studies recommended to use sEMG recording during locomotion such as walking or running, it is because the EMG is much stronger during dynamic activities. Similar suggestions were also made by Hu et al (2007) who recommended the use of EMG during activity.
Based on the above mentioned studies, it is evident that there is a scope for the use of EMG of the lower back to diagnose the lower back ailments. There are also disagreements regarding the reliability and efficiency of EMG of the lower back while maintaining the posture. From the above studies, it appears that the use of EMG during activity is perhaps more reliable and may yield more reliable outcomes. Based on the above, literature was further reviewed to determine the various types of activities that can be studied for the low back ailments analysis using EMG of the lower back.

2.4: Activation patterns during different walking speed

Many people who have chronic low back pain (LBP) experience problems with walking. On average, they walk more slowly than healthy walkers (Khodadadeh S et al., 1988 and Spenkelink CD et al., 2002), some researchers suggested this was related to the pain-adaptation model (Lind et al… 1991). To inhibit the activity of the agonist, the antagonist augment will be used and this will minimize the movement of the painful segment (Lamoth CJC et al., 2004).

Patients with chronic LBP may alter the neuromuscular control of the gross motor activities such as locomotion, by way of ‘protective guarding’ or ‘splinting’ (Ahern et al…1990 & Marras et al…1986).

Trunk muscles have been divided into two muscle systems (Bergmark A,…1989): the local system ensures the stability and the global system enables the movements. There are two distinct types of activation patterns: Local system muscles are permanently active at low levels (Comerford MJ et al…2001), which are independent to movements. Conversely, muscles of the global system act to initiate movements leading to movement dependent phasic activation patterns. Recently, the global system was subdivided further into the global stabilizing and the global mobilizing systems (Anders C et al…2006). Global stabilizers complement the function of the local system by controlling and limiting movements by means of eccentric activation characteristic (Comerford MJ et al…2001).

Work reported by Anders C (Anders C et al…2006) investigated the trunk muscle activation patterns of healthy subjects under different walking speed. Fifteen healthy subjects were investigated when walking on a treadmill at low speed. Five different trunk muscles were investigated using the surface sEMG. Data was time normalized according to stride time and averaged. They observed that the phase of activation patterns of sEMG remained similar with the increase in walking speed. The average amplitude of sEMG varies proportionally with the change in walking speed.
2.5: Activation pattern of CLBP under perturbation walking speed

The study attempted to examine the relationship of trunk-pelvis coordination to overall gait stability for both healthy and LBP persons, persons with LBP can be expected to have difficulties in dealing with perturbations. They hypothesized that in healthy walking, the timing between trunk and pelvic rotations, as well as erector spinae (ES) activity varies systematically with walking velocity, whereas a comparable velocity-dependent adaptation of trunk–pelvis coordination is often reduced or absent in persons with low back pain (LBP). Twelve LBP subjects were examined in controlled conditions. The results indicated that compared to healthy controls, individuals with LBP exhibited a reduced ability to adapt trunk–pelvis coordination and ES muscle activity to changes in velocity. Altered coordination and muscular control may reflect an attempt to stabilise the spine and prevent the occurrence of unexpected perturbations.

2.6: Effect of activation pattern during pain and fear of pain

In Lamoth’s studied the effect of induced pain and fear of pain on trunk coordination and back muscle activity during walking. Based on their earlier work (Lamoth et al., 2002b), they believed that a person with chronic LBP may encounter problems in adjusting thorax-pelvis coordination with increasing walking velocities, while at low walking velocities between thoracic and pelvis rotations may be observed. On the other hand, the amplitude of segment oscillations should be unaffected at low walking velocities for the LBP persons. (Lamoth et al., 2002b).

In Lamoth’s study they has 12 healthy subjects, hypertonic saline was used to induce acute pain while isotonic saline was used to induce fear of pain. Unpredictable electric shocks were used for fear of impending pain while participants walked on the treadmill. They observed that trunk kinematics was not affected by the manipulations. Induced pain led to an increase in EMG variability and induced fear of pain led to a decrease in mean EMG amplitude during double stance.

From this study, it is observed that the altered gait observed in low back pain patients is probably a complex evolved consequence of a lasting pain, rather than a simple immediate effect.

Vogt L has conducted a study of the neuromuscular control of walking with chronic low-back pain. They studied seventeen idiopathic low-back pain male subjects and 16 healthy volunteers participated in the study. Hip joint ROMs in the sagittal plane and neuromuscular activities of erector spinae [L3, T12], gluteus maximums and biceps femoris were recorded on one randomly selected body side in
Chapter 2 Literature review

each group. (Vogt L et al…2003)

Analysis using the Student’s t-test revealed significant high differences for hip joint range of motion, stride time and significantly earlier onsets of the lumbar spine and hip extensors of the back pain sufferers compared with the healthy controls.

2.7: The relationship between walking and gait analysis

Walking appears to be composed of quite steady coordination mades, specific phase and frequency relations between cyclical movement of limbs, pelvis, trunk, and head. Coordination between trunk and pelvis and the activity of associated musculature such as erector spinae muscles have proven to be useful entry point of the human gait.(Lamoth CJC al…2002) When walking speed is varied, timing and variability of trunk-pelvis coordination and ES activity change systematically, presumably to cope with perturbations and to preserve stable gait patterns. (Crosbie Jal…1997) In unimpaired gait, increasing walking velocity change the phase difference, or relative phase, between transverse thoracic and pelvis rotations from more or less in-phase toward more anti-phase coordination. During the increase in walking speed the lumbar erector spinae activity displays a biphasic activity pattern with peak activity around foot contact and has little activity during swing phases.
Chapter 3 Experimental Setup and Protocol

This thesis reports experimental work conducted to test the research question and identify the differences, if any, between the cohort of healthy back participants and of people suffering from LBP based on surface electromyogram (sEMG). As discussed in the earlier chapters, experiments were aimed at identifying differences in the two groups using sEMG recorded during the time the participants walked on a treadmill. In the following sections, the experimental setup and the experimental protocol has been described.

3.1: Experimental Setup

In this section, the criterion for subject selection for the two cohorts - both healthy and LBP group- has been discussed. This is followed by a discussion regarding the types of locomotion studied in this work. The selection of the lumbar muscles has also been explained. At the end of this section, the detail of the equipment used for the experiments has been explained.

3.1.1: The methodology of subject selection

3.1.1a: Ethics approval and experiment authority

All preliminary experiments were conducted at RMIT University (Australia) in 2007 followed by experiments conducted at The University of Hong Kong in early 2008. Duchess of Kent Children’s Hospital provided the access to LBP patients. The experiments were approved by RMIT human research ethics committee, and the Institutional review board of the University of Hong Kong/ Hospital Authority of the Hong Kong West Cluster.

3.1.1b: Subject selection

Nine healthy men (age between 18 to 37 years, for details of demographic data see table 3.1) with no history of low back pain (LBP), or no history of LBP occurred in the past 2 years, voluntarily participated in this study. This study required subjects not to have any injuries to their lower extremities, any disorders related to the locomotion apparatus or leg length discrepancy of greater then 1cm. Four LBP (age between 28 to 53 - for details of demographic data see table 3.1) subjects were
Chapter 3 Experimental Setup and Protocol

examined by the hospital, using standard LBP identification method such as SLR test (straight leg raising), check the range of motion (flexion test, extension test, rotation test). All four LBP patients voluntarily participated and were identified as non-specific LBP and mechanical LBP cases.

Informed written consent and (Oswestry Disability Index) questionnaire were obtained from each volunteer (Chowa J H W et al….2005). The questionnaire were written in Chinese when the experiments were conducted in Hong Kong For the experiment conducted in Australia the questionnaire was written in English.

More information of exclusion criteria:

1) Arthritidis (for example, osteoarthritis, and rheumatoid arthritis).
2) Neuromuscular disorders including collagen disorders, non-articular rheumatism including fibro myalgia, seizure disorders, sleep disorders, cerebrovascular diseases, previous trauma of the spine resulting in neurological deficit.
3) Spinal disease such as disc Herniation, disc protrusion, spine degenerative, demyelinating disease, spinal cord disorders, disorders of the peripheral nervous system, or any surgery of the spine or at lower extremities (in pass 12-24 months).
4) Any recent injuries at the spine or lower extremities are not suitable for our study.

Table 3.1: The general information of all participants in this experiment

<table>
<thead>
<tr>
<th></th>
<th>Healthy Subjects (n=9)</th>
<th>Patients with LBP (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>177.1 ± 7.04</td>
<td>171.8 ± 3.3</td>
</tr>
<tr>
<td></td>
<td>(167-188)</td>
<td>(168-175)</td>
</tr>
<tr>
<td>Hight (cm)</td>
<td>70 ± 11.7</td>
<td>71.5 ± 4.1</td>
</tr>
<tr>
<td></td>
<td>(50-84)</td>
<td>(68-76)</td>
</tr>
<tr>
<td>Body mass index</td>
<td>22.2 ± 2.6</td>
<td>24.3 ± 1.6</td>
</tr>
<tr>
<td>(kg/m^2)</td>
<td>(17.9- 25.1)</td>
<td>(22.4-26.1)</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>29. 8 ± 6.5</td>
<td>39 ± 12.0</td>
</tr>
<tr>
<td></td>
<td>(18-37)</td>
<td>(28-53)</td>
</tr>
</tbody>
</table>

Data given as mean ± Standard Deviation (Range)
Chapter 3 Experimental Setup and Protocol

3.1.2: Type of locomotion conduct in the experiment

The limitations of using sEMG to investigate the trunk muscle activity during human locomotion are: 1) It is limited to the superficial muscle where the electrodes are placed. 2) Several studies have identified the patterns of the superficial trunk muscle have very complex phase. This complex phase was associated with the bursts of muscle activity, movements of the trunk and periods of high reactive force, e.g. foot strike (FS) (Saunders et al….2004 & Callaghan JP et al….1999 & Novacheck TF….1995).

In our experiment, we will only focus on dynamic locomotion in different walking speed and the experiment will only conduct on the treadmill.

3.1.3: Lumbar Muscle selection of the experiment

Recent studies have shown that the control of trunk movement is associated with the superficial trunk muscles, they also suggest that the deep intrinsic muscles of the spine, such as: transverses abdominis (TrA) and multifidus (MF), provide an important and distinct contribution to the control of lumbo-pelvic stability at an inter-segmental level (Creswell AG et al…1994 & Hodges PW et al…2000 & Hodges PW et al…1997). In our experiment, we focused on the multifidus (MF) because it provided the most important and relevant information about the stability of the lumbar-pelvic during walking.
### Table 3.2: shows the location of the electrode placement on the lumbar area

<table>
<thead>
<tr>
<th>Channel assign</th>
<th>Muscle</th>
<th>Electrode placement location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel 1 (Left)</td>
<td>Erector Spinae (ES) (longissimus, ES 1/r)</td>
<td>Over palpable bulge of muscle at left L1 level (approximately 2 to 3cm lateral midline), and the direction is vertical (perpendicular to the direction of ES).</td>
</tr>
<tr>
<td>Channel 2 (Right)</td>
<td>Erector Spinae (ES) (longissimus, ES 1/r)</td>
<td>Over palpable bulge of muscle at right L1 level (approximately 2 to 3cm lateral midline), and the direction is vertical (perpendicular to the direction of ES).</td>
</tr>
<tr>
<td>Channel 3 (Left)</td>
<td>Multifidus (lumbalis, MF 1/r)</td>
<td>The electrode place at left L4 level (approximately 2 to 3cm lateral midline and 1 to 1.5cm from the line between PSIS and 1st palpable spinuous process), and the direction is vertical (perpendicular to the direction of MF).</td>
</tr>
<tr>
<td>Channel 4 (Right)</td>
<td>Multifidus (lumbalis, MF 1/r)</td>
<td>The electrode place at left L4 level (approximately 2 to 3cm lateral midline and 1 to 1.5cm from the line between PSIS and 1st palpable spinuous process), and the direction is vertical (perpendicular to the direction of MF).</td>
</tr>
</tbody>
</table>

Posterior superior iliac spine (PSIS)
3.1.4: Equipment details and design

3.1.4a: EMG recording system

“Bagnoli™ Desktop EMG Systems” (Delsys, Boston, MA, USA) was used in this research study; it had 16 channels of input signal and 50 Hz interference check when recording sEMG. This EMG system was used because of the additional features such as: 1) Amplifier Saturation Check, 2) Visual LED Indicators, 3) Audio Indicator provision, 4) Ultra light and rugged input module cable and 5) Pre-amplifier function in the electrodes can reduce the noise level.

The gain of the EMG recording had set at 1000 and the double differential electrodes (DE-3.1, BagnoliTM, 41 x 20 x 5 mm) have been used in the recording.

The signals were recorded and processed in the “EMGworks® 3.1: Signal Acquisition and Analysis Software”. Total of seven channels have been used in the experiment.
Table 3.3: Electrode placement of all the channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>Location of electrode placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel 1</td>
<td>Left ES</td>
</tr>
<tr>
<td>Channel 2</td>
<td>Right ES</td>
</tr>
<tr>
<td>Channel 3</td>
<td>Left MF</td>
</tr>
<tr>
<td>Channel 4</td>
<td>Right MF</td>
</tr>
<tr>
<td>Channel 5</td>
<td>Left Foot Sensor</td>
</tr>
<tr>
<td>Channel 6</td>
<td>Right Foot Sensor</td>
</tr>
<tr>
<td>Reference signal (Ground)</td>
<td>Clavicle Bone (CB)</td>
</tr>
</tbody>
</table>

Figure 3.2: The main amplifier and Sensor input module of Delsys EMG recording system

The photo was taken during the experiment
3.1.4b: Foot Sensor design

The purpose of the foot sensor was to help identify the time of the heel strike and to measure the time between heel strike and lumbar muscle activation. For this purpose, the foot sensor was purpose designed and assembled at RMIT University at the electronic design workshop. The sensor consists of two copper plates fixed on one variable resistive material frame. The frame was located between two copper plates. The frame behaved like a variable resistor. The initial resistance of the frame was approximately 3MΩ, but when the pressure was applied to the frame, the resistance decreased from 3MΩ to approximately 500Ω. The resistance level is inversely proportional to the pressure and the change in resistance determines the temporal location of the heel strike.

The dimension of the copper plate is: 60mm in diameter and only conductive at one side, 20mm from the edge was non-conductive (see figure 3.4), and the dimension of the conductive frame was 30mm x 30mm.
Chapter 3 Experimental Setup and Protocol

Figure 3.4: The anatomy of Foot Sensor design and the use of material

Figure 3.5: Circuit design for connecting the foot sensor to the Delsys Electrode

The detail calculation of the value of the R1 refer to Appendix D
Chapter 3 Experimental Setup and Protocol

3.1.4c: Reference Electrode

In order to record the optimum sEMG signal during the walking or running experiment, proper grounding location is required. It is essential that a good grounding point should be close to the bone and have minimum muscle. In these experiments, Clavicle Bone (CB) was used as the grounding location (see figure 3.6). The electrode used for grounding was 3M Red Dot\textsuperscript{tm} 2330 (dimension 2.2 x 3.2 cm).

The grounding electrode was connected by the crocodile clip and connected to the Delysis recording system as a reference signal. Synchrony recording mode was enabled for reference signal and the sEMG.

Figure 3.6: Shows the grounding location of the participant

3.1.4d: Treadmill Information

The treadmill used in the experiment is the “Life Fitness T7 treadmill” the speed for walking was 4.5km/hours with zero degree angle and the running was at 9km/hour with zero degree angle.
3.2: Experimental Protocol

All participants were required to complete the questionnaire and the consent declaration before the experiment. The participants were explained in detail the experiment and the equipment and were informed that they could discontinue the experiment whenever they so wished and without giving any reason. The equipment setup and protocol prior to the experiment is given below in five steps:

1) Skin preparation – The participants were required to clean their skin with any medical use of swab which contain 70% of alcohol and remove all the body hair at the location which the electrode will be placed. This treatment helps to reduce the skin impedance from about 3MΩ to less than 500kΩ (typical).

2) Electrode placement – The first step was the identification of the location of lumbar muscle L1 and PSIS. After this, water based markers were used to mark the site and to connect these three point together (see figure 3.8). The electrodes were attached to the trunk with neoprene bands at the second lumbar vertebra (L1) and the fourth lumbar vertebra (L4) in both right and left position. Electrodes were placed at 2 to 3 cm lateral from the vertebral column. The electrode placement was dependent on the surface area of the upper trunk and the length of the erector spinae.

Figure 3.7: Shows the muscle direction of the MF
3) Foot sensor – connect the foot sensor to the Delsys EMG recorder then check the battery and grounding connection. Place the sensor inside the shoes at the location of the heel (see figure 3.9).

Figure 3.9: Location of the foot sensor placement

4) Internal setting of the Delsys recorder – The sampling frequency for surface EMG at 1 KHz for these electrodes at lumbar and foot sensor. Check the total number of channels and the amplification gain on the main amplifier. The number of channels should be seven and the amplification gain should set as 1000 in order to
get the clear EMG signals. All raw data will process by “EMGworks® 3.1: Signal Acquisition and Analysis Software” first, then the data will be analyses in Matlab R2007b (Mathworks, Natic, MA, USA)

5) Try to relax the participant before they start the experiment, such as ask them some friendly questions. All the subjects are required to take a trial exercise on the treadmill for 2 minutes before the actual experiment take place. These allow them to familiar with the walking speed and minimize the recording errors. The speed of the trial walk should be the same as actual experiment: 4.5km/hour for walking and 9km/hour for running. To kept the walking speed constant will give us better idea of what is the difference in the sEMG for healthy and LBP patients.

6) Recording start after participant habituated the treadmill’s velocity, we want the participant to walk in their normal posture. Subjects in both healthy and LBP group were required to perform walking experiment. The experiments were performed on the treadmill at two fixed speed for approximately 10 minutes and, participant will allow to stop when they feeling pain or muscle fatigue.

Figure 3.10: Shows the experimental protocol for each exercise. (Saunders W S et al...2004)
Chapter 3 Experimental Setup and Protocol

7) Rest time of 5 minutes is given to all subjects after finish the first part of the experiment. This can avoid muscle fatigue prior of the start of the next experiment. Furthermore, the reason we need longer experiment time was, it allow us to compare the duration difference between erector spinae (ES) and Posoas major muscle activation state and the magnitude variance during time.

8) Check stability of the surface electrode on lumbar after finish the first part of the experiment; see if they need to be replacing by the new one.

9) Remove the surface electrode on lumbar from the participant and Thank you for their voluntary participate.
Chapter 4 Methodology

4.1: Introduction:

During the recording of the experiment the signal was segmented into 1 minute sections. The 1st minute corresponded to the start of the exercise and the 10th minute to the end of the walking/running exercise. After the signal had been processed by “EMGworks® 3.1: Signal Acquisition and Analysis Software”, then this was further analyzed using Matlab R2007b (Mathworks, Natic, MA, USA) for the further analysis. The data analysis has been explained in the following three sections.

4.2: Signal Processing Method

sEMG signal will reconstructed by the loademg3.m program. This allows obtaining each individual channel from the raw data consisting of the 16 channels. This data is then analysed to determine if there is any DC offset in the raw signal. DC offset will shift up the signal from zero voltage level (see figure 4.1). The DC offset was removed by DC subtraction method. In Matlab the function detrend allow us to normalize the signal and start at zero.

Figure 4.1: The original raw signal and the adjusted signal.
The next step was to filter the signal to remove noise. For this purpose, Peridogram was computed to obtain the power spectral density (PSD) of the signal. This function allows us to identify the different frequency levels in the signal.

**Figure 4.2: The Power spectral density (PSD) of the raw signal**

![Power spectral density (PSD) of the raw signal](image1)

After obtaining the spectral information, it was then decided if the signals was having the expected spectrum and if spectral filtering was required. Notch filter at 50, 100 and 150 Hz to cut off the main noise in the PSD, and bandpass filter with lower cutoff of 20 and higher cutoff of 200 Hz was used. The order of the bandpass filter is 6 orders.
If we now compare the original raw signal in figure 4.2 with the filtered signal in figure 4.3, the noise frequency at 50Hz and above 200 Hz appears very small.

**Figure 4.3: The Power spectral density (PSD) of the signal after filtering**

If we now compare the original raw signal in figure 4.2 with the filtered signal in figure 4.3, the noise frequency at 50Hz and above 200 Hz appears very small.

**Figure 4.4: Comparison between original signal and filtered signal**
4.3: Activation period analysis method

Calculation of the activation period of the sEMG signal required the determination of the background activity and identifying a suitable threshold to segment the signal. This required the computation of 1) The threshold of the average EMG, 2) The RMS (Root Mean Square) of the EMG.

4.3.1: Threshold calculation method

First calculate the RMS value of the filtered signal, and then sort the signal amplitude in the ascending order to obtain the histogram. In this section, the average RMS value for the threshold needed to be within 80% to 90% of the sample population. Using the RMS of the signal and an average value of the RMS, the signal was segmented to obtain the activation and deactivation period.

Figure 4.5: The RMS signal with threshold level

![Figure 4.5: The RMS signal with threshold level](image)

Figure 4.6: The flow diagram of the activation period analysis method

![Figure 4.6: The flow diagram of the activation period analysis method](image)
4.4: **Amplitude analysis method**

This step was to compare the amplitude of each gait cycle for the experiment. The total number of minutes of each experiment would vary depending on the subjects; normally healthy subjects completed the experiment which is 20 minutes while the LBP subjects were often unable to complete the experiments. For the LBP subjects they may not able to complete the whole experiment so the time may be shorter for them.

After sorting the data in ascent order, the signal from 1st minute to the last minute were plotted into same graph (see figure 4.7) but using different color for each temporal segment. After this, the first order and second order statistical variance of the signal for each minute and for each experiment was computed.

**Figure 4.7: The EMG signal after sort in ascent order**

**Figure 4.8: The flow diagram of the amplitude analysis method**
Chapter 5: Results and Observation

5.1: Introduction

It is commonly understood that the relationship between muscle fatigue of lumbar muscles and low back pain is closely related. Muscle fatigue causes an increase in the amplitude of the recorded muscle activity (Keller et al...2000). It is believed that people with low back ailments would have an earlier onset of muscle fatigue and hence such people would have a faster increase in the magnitude of surface electromyogram compared with the people with healthy back.

During the onset of muscle fatigue, the body attempts to recruit other muscles to achieve the same action. This would result in an increase in amplitude of the sEMG signal. This suggests that people with low back ailments would alter their muscle activation strategy when they are actively using these muscles, while people with healthy backs will not (Keller et al...2000). This would result in the larger variations in the activation/deactivation times of people with low back ailments compared with people with healthy backs. The aim of the experiments conducted was to test this hypothesis. Experiments were conducted on two groups of participants; with healthy backs, and suffering from low back pain (LBP).

The results of the experiments have been presented in tables in this chapter. Table 5.1.4 gives a brief of all the results tables. Figure 5.2 provide an example of the sEMG recordings. A brief statement of the observations related to each of the tables is provided following each table.
Chapter 5: Results & Observation

5.1.1: sEMG recording indicating activation and deactivation period of lumbar muscle

Figure 5.1: sEMG recording indicating activation and deactivation period of lumbar muscle
## Overview of key research data

<table>
<thead>
<tr>
<th>Subjects condition</th>
<th>Type of experiment</th>
<th>Placement of electrode</th>
<th>Observation table &amp; figures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LBP (Low Back Pain)</strong></td>
<td>Walking</td>
<td>Channel 1 (Left L1 / L2)</td>
<td>5.2a</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 2 (Right L1 / L2)</td>
<td>5.2b</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 3 (Left L4 / L5)</td>
<td>5.2c</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 4 (Right L4 / L5)</td>
<td>5.2d</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 1 (Left L1 / L2)</td>
<td>5.3a</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 2 (Right L1 / L2)</td>
<td>5.3b</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 3 (Left L4 / L5)</td>
<td>5.3c</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 4 (Right L4 / L5)</td>
<td>5.3d</td>
</tr>
<tr>
<td><strong>Healthy</strong></td>
<td>Walking</td>
<td>Channel 1 (Left L1 / L2)</td>
<td>5.4a</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 2 (Right L1 / L2)</td>
<td>5.4b</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 3 (Left L4 / L5)</td>
<td>5.4c</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 4 (Right L4 / L5)</td>
<td>5.4d</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 1 (Left L1 / L2)</td>
<td>5.5a</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 2 (Right L1 / L2)</td>
<td>5.5b</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 3 (Left L4 / L5)</td>
<td>5.5c</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 4 (Right L4 / L5)</td>
<td>5.5d</td>
</tr>
<tr>
<td><strong>Comparison between Healthy &amp; LBP subjects for all channels</strong></td>
<td>Walking</td>
<td>All Channels</td>
<td>5.6a</td>
</tr>
<tr>
<td>Healthy &amp; LBP subjects</td>
<td>Running</td>
<td>All Channels</td>
<td>5.6b</td>
</tr>
</tbody>
</table>
Chapter 5: Results & Observation

5.2: Analysis method using activation period

Table 5.1a: The average activation period of the lumbar muscle of each cycle for healthy & LBP subjects in one minute time frame.

<table>
<thead>
<tr>
<th>Channel 1</th>
<th>Activation period (Sec)</th>
<th>Healthy Subjects 1 &amp; 2 Walking in Speed of 4.5km/h at the 4th Minutes</th>
<th>LBP Subject 1 Walking in Speed of 4.5km/h at the 4th Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left L1 / L2</td>
<td>0.5170037</td>
<td>0.6107201</td>
<td>0.6508092</td>
</tr>
<tr>
<td>STDEV</td>
<td>0.1090679</td>
<td>0.0776827</td>
<td>0.0891964</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0118958</td>
<td>0.0060346</td>
<td>0.007956</td>
</tr>
<tr>
<td>Right L1 / L2</td>
<td>0.5495558</td>
<td>0.5345298</td>
<td>0.658647</td>
</tr>
<tr>
<td>STDEV</td>
<td>0.0686539</td>
<td>0.0471232</td>
<td>0.0668948</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0047134</td>
<td>0.0022206</td>
<td>0.0044749</td>
</tr>
<tr>
<td>Left L4 / L5</td>
<td>0.5861328</td>
<td>0.6923265</td>
<td>0.6830706</td>
</tr>
<tr>
<td>STDEV</td>
<td>0.0615182</td>
<td>0.0638791</td>
<td>0.0526281</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0037845</td>
<td>0.0040805</td>
<td>0.0027697</td>
</tr>
<tr>
<td>Right L4 / L5</td>
<td>0.6769531</td>
<td>0.6157978</td>
<td>0.7100497</td>
</tr>
<tr>
<td>STDEV</td>
<td>0.0909581</td>
<td>0.0430115</td>
<td>0.0596519</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0082734</td>
<td>0.00185</td>
<td>0.0035583</td>
</tr>
</tbody>
</table>
Observations for table 5.1a

- The average activation period for healthy subject 1 and 2 in all channels were observed to be very similar; the largest variation between two subjects is in Channel 3. The standard deviation in Channel 3 for both healthy subjects is approximately 10% and the activation duration between them is $(0.6923265 - 0.5861328 =) 0.106$ seconds, approximately 15% which is relatively small.
- The average activation period between healthy and LBP subjects in all channels were observed to be similar, the largest variation takes place in Channel 2. The standard deviation in Channel 2 for all 3 subjects is approximately 10% and the activation duration between them is $(0.658647 - (0.5495558 + 0.5345298)/2 =) 0.117$ seconds, approximately 18%.
- It is observed that standard deviation is small compared with the mean values. Based on this, it can be stated that the mean is a good representation of the values.
- Based on the observation, the activation period for all channels in both healthy and low back ailment subjects are relatively stable when the walking speed remains constant.
### Table 5.1b: The average activation period of the lumbar muscle for healthy subjects in one minute time frame different walking speed

<table>
<thead>
<tr>
<th>Channel</th>
<th>Activation period (Sec)</th>
<th>Healthy Subjects 1 &amp; 2</th>
<th></th>
<th>Healthy Subject 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Walking in Speed of 4.5km/h at the 4&lt;sup&gt;th&lt;/sup&gt; Minutes</td>
<td>Walking in Speed of 2.25km/h at the 2&lt;sup&gt;nd&lt;/sup&gt;Minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel 1</td>
<td>Activation period (Sec)</td>
<td>0.5170037</td>
<td>0.6107201</td>
<td>0.9831687</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STDEV</td>
<td>0.1090679</td>
<td>0.0776827</td>
<td>0.1234614</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Variance</td>
<td>0.0118958</td>
<td>0.0060346</td>
<td>0.0152427</td>
<td></td>
</tr>
<tr>
<td>Channel 2</td>
<td>Activation period (Sec)</td>
<td>0.5495558</td>
<td>0.5345298</td>
<td>0.954895</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STDEV</td>
<td>0.0686539</td>
<td>0.0471232</td>
<td>0.1472904</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Variance</td>
<td>0.0047134</td>
<td>0.0022206</td>
<td>0.0216945</td>
<td></td>
</tr>
<tr>
<td>Channel 3</td>
<td>Activation period (Sec)</td>
<td>0.5861328</td>
<td>0.6923265</td>
<td>0.9543186</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STDEV</td>
<td>0.0615182</td>
<td>0.0638791</td>
<td>0.0760613</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Variance</td>
<td>0.0037845</td>
<td>0.0040805</td>
<td>0.0057853</td>
<td></td>
</tr>
<tr>
<td>Channel 4</td>
<td>Activation period (Sec)</td>
<td>0.6769531</td>
<td>0.6157978</td>
<td>0.9606934</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STDEV</td>
<td>0.0909581</td>
<td>0.0430115</td>
<td>0.0894835</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Variance</td>
<td>0.0082734</td>
<td>0.00185</td>
<td>0.0080073</td>
<td></td>
</tr>
</tbody>
</table>

**Observations for table 5.1b:**
- Subject 3 had appears almost 50% longer in average activation period than Subject 1 & 2 when the walking speed decreased to 2.25km/h.
- The value of standard deviation had appears higher when the walking speed decrease.
5.3: Amplitude analysis method

5.3.1: Subjects with Low Back Ailments

Table 5.2a (Channel 1 – Walking): The variance of amplitude for each minute time frame for four subjects with low back ailments

<table>
<thead>
<tr>
<th>Channel 1 (Left L1 / L2)</th>
<th>Time (Minutes)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>4.64E-11</td>
<td>4.40E-11</td>
<td>4.77E-11</td>
<td>5.87E-11</td>
<td>5.93E-11</td>
<td>5.91E-11</td>
<td>5.04E-11</td>
<td>5.38E-11</td>
<td>N/A</td>
<td>N/A</td>
<td>5.24E-11</td>
<td></td>
</tr>
<tr>
<td>Subject 2</td>
<td>2.67E-11</td>
<td>2.61E-11</td>
<td>2.70E-11</td>
<td>2.46E-11</td>
<td>2.46E-11</td>
<td>2.49E-11</td>
<td>2.60E-11</td>
<td>2.46E-11</td>
<td>2.48E-11</td>
<td>2.44E-11</td>
<td>2.54E-11</td>
<td></td>
</tr>
<tr>
<td>Subject 3</td>
<td>8.21E-10</td>
<td>8.48E-10</td>
<td>6.82E-10</td>
<td>5.50E-10</td>
<td>6.25E-10</td>
<td>4.70E-10</td>
<td>6.73E-10</td>
<td>8.53E-10</td>
<td>9.21E-10</td>
<td>6.85E-10</td>
<td>7.13E-10</td>
<td></td>
</tr>
<tr>
<td>Subject 4</td>
<td>3.73E-11</td>
<td>3.65E-11</td>
<td>3.30E-11</td>
<td>3.69E-11</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>3.59E-11</td>
<td></td>
</tr>
</tbody>
</table>
Observation for table and figure 5.2a:
- There is an intra-subject variation between subject 3 and the others, but within each subject the variation is small. Figure 5.2a shows 3 relatively flat lines of variance, while subject 3 shows a higher variance than the others and it is not as consistent as the others. Although the variance of subject 3 is higher, overall it is still relatively small (STDEV is less than 10%) compare with the amplitude. Details of average amplitude and standard deviation have already been explained in chapter 4 – Methodology.
- Only small variation of variance has been observed through both Table 5.2a and Figure 5.2a, it is clear that after a period of walking experiment, all subjects’ EMG signals are consistent.
Table 5.2b (Channel 2 – Walking): The variance of amplitude for each minute time frame for four subjects with low back ailments

<table>
<thead>
<tr>
<th>Channel 2 (Right L1 / L2)</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Subject 1</td>
<td>3.34E-11</td>
<td>2.84E-11</td>
</tr>
<tr>
<td>Subject 2</td>
<td>1.18E-11</td>
<td>1.12E-11</td>
</tr>
<tr>
<td>Subject 3</td>
<td>8.86E-11</td>
<td>1.03E-10</td>
</tr>
<tr>
<td>Subject 4</td>
<td>7.98E-11</td>
<td>6.06E-11</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.2b:

- The intra-subject variation is small while the average values of the variance for all subjects in Channel 2 are between 1.05E-11 to 9.53E-11. The variation within each subject is relatively small, the difference between the largest variance and the mean of variance in Channel 3 (refer to figure 5.2b) is 2.97E-11 (= 1.25E-10 - 9.53E-11), which is approximately 23%.
- In both Table 5.2b and Figure 5.2b, it is observed that the sEMG signals of Channel 2 for all LBP subjects are in a consistent level during walking experiment.
### Table 5.2c (Channel 3 – Walking): The variance of amplitude for each minute time frame for four subjects with low back ailments

<table>
<thead>
<tr>
<th>Channel 3 (Left L4 / L5)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>3.31E-11</td>
<td>3.53E-11</td>
<td>4.45E-11</td>
<td>2.76E-11</td>
<td>2.62E-11</td>
<td>2.66E-11</td>
<td>2.40E-11</td>
<td>2.44E-11</td>
<td>N/A</td>
<td>N/A</td>
<td>3.02E-11</td>
</tr>
<tr>
<td>Subject 2</td>
<td>4.03E-11</td>
<td>6.61E-11</td>
<td>6.69E-11</td>
<td>1.54E-11</td>
<td>1.69E-11</td>
<td>1.52E-11</td>
<td>1.62E-11</td>
<td>1.69E-11</td>
<td>1.70E-11</td>
<td>1.60E-11</td>
<td>2.87E-11</td>
</tr>
<tr>
<td>Subject 3</td>
<td>8.37E-11</td>
<td>1.65E-10</td>
<td>1.44E-10</td>
<td>1.38E-10</td>
<td>1.21E-10</td>
<td>1.30E-10</td>
<td>1.33E-10</td>
<td>1.27E-10</td>
<td>9.25E-11</td>
<td>7.34E-11</td>
<td>1.2E-10</td>
</tr>
<tr>
<td>Subject 4</td>
<td>6.58E-11</td>
<td>2.25E-11</td>
<td>1.85E-11</td>
<td>1.95E-11</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>3.16E-11</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.2c:
- Subject 3 has a relatively larger variance than the other subjects, but the difference is still minor given that the range of variance is within E-10.
- The observations from both table 5.2c and figure 5.2c have clearly showed the average sEMG signal on Channel 3 for all LBP subjects are very consistent.
Table 5.2d (Channel 4 – Walking): The variance of amplitude for each minute time frame for four subjects with low back ailments

<table>
<thead>
<tr>
<th>Time (Minutes)</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average of variance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.26E-11</td>
<td>1.39E-11</td>
<td>6.43E-11</td>
<td>2.12E-11</td>
</tr>
<tr>
<td>2</td>
<td>2.13E-11</td>
<td>1.55E-11</td>
<td>8.42E-11</td>
<td>1.49E-11</td>
</tr>
<tr>
<td>3</td>
<td>2.41E-11</td>
<td>1.46E-11</td>
<td>6.63E-11</td>
<td>1.39E-11</td>
</tr>
<tr>
<td>4</td>
<td>2.84E-11</td>
<td>1.04E-11</td>
<td>8.04E-11</td>
<td>1.32E-11</td>
</tr>
<tr>
<td>5</td>
<td>3.43E-11</td>
<td>1.15E-11</td>
<td>7.66E-08</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>3.02E-11</td>
<td>1.09E-11</td>
<td>6.88E-11</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>2.72E-11</td>
<td>1.28E-11</td>
<td>7.27E-11</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>1.26E-07</td>
<td>1.12E-11</td>
<td>6.32E-11</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>N/A</td>
<td>1.19E-11</td>
<td>5.22E-11</td>
<td>N/A</td>
</tr>
<tr>
<td>10</td>
<td>N/A</td>
<td>1.17E-11</td>
<td>4.45E-11</td>
<td>1.58E-11</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.2d:

- Subject 1 is relatively stable from the start to the 7th minute, but there is a sudden change in variance at the last minute. The value increased from 2.72E-11 to 1.26E-07 for subject 1 in the last minute.
- Variance for Subject 3 also suddenly changed from 8.04E-11 to 7.66E-08 at the 5th minute.
- Based on the above observation from Channel 4 of walking, the variances are relatively small in all channels. Although there are sudden change of variances in subject 1 and 3, it is most likely that those are the effect of artifact signals generated from the Delsys recording system. In summary, it is clear that the amplitude of the sEMG signal is consistently stable.
Chapter 5: Results & Observation

5.3.1a: Observation summary for table and figure from 5.2a to 5.2d (Walking – LBP subjects)

The intra-subject variation in the amplitude of recorded sEMG during walking was low in most subjects for all channels. Observation from Table 5.2a - 5.2d and Figure 5.2a - 5.2d show nearly straight line of variance in subject 1, 2 and 4 for all channels. Subject 3 has slightly higher variance in all channels, but it is not as consistent as the others. There is a sudden change in variance of subject 3 in channel 4; it is most likely a result of the artifact signal generated from the Delsys recording system. Overall the variance of subject 3 is relatively consistent given that the range of variance is always within E-10, which is very similar to the other subjects in the same condition.
Table 5.3a (Channel 1 – Running): The variance of amplitude for each minute time frame for four subjects with low back ailments

<table>
<thead>
<tr>
<th>Channel 1 (Left L1 / L2)</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Subject 1</td>
<td>2.21E-10</td>
<td>2.98E-10</td>
</tr>
<tr>
<td>Subject 2</td>
<td>7.83E-11</td>
<td>1.53E-10</td>
</tr>
<tr>
<td>Subject 3</td>
<td>5.09E-09</td>
<td>6.63E-09</td>
</tr>
<tr>
<td>Subject 4</td>
<td>2.70E-11</td>
<td>3.31E-10</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.3a:

- Subject 2 and 3 show highly inconsistent of variance during running. Subject 3 has the highest variance at the 2nd minute, and it become stable after the 5th minute. Subject 2 shows consistent variance from the start to 7th minute, then it increases from 7th to 9th minute.
- Subject 1 and 4 have consistent variance throughout the experiment.
- Based on the observation from both table 5.3a & figure 5.3a, it clearly shows an increase of variance during running. It also suggests that the amplitude of sEMG for both subject 2 and 3 may have significant variation during the running experiment.
### Table 5.3b (Channel 2 – Running): The variance of amplitude for each minute time frame for four subjects with low back ailments

<table>
<thead>
<tr>
<th>Channel 2 (Right L1 / L2)</th>
<th>Time (Minutes)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Subject 1</td>
<td>3.63E-10</td>
<td>6.67E-10</td>
<td>1.61E-08</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>5.70E-09</td>
</tr>
<tr>
<td>Subject 2</td>
<td>4.82E-11</td>
<td>6.12E-11</td>
<td>8.42E-11</td>
<td>1.97E-10</td>
<td>3.93E-10</td>
<td>3.92E-10</td>
<td>5.53E-10</td>
<td>6.54E-10</td>
<td>5.52E-10</td>
<td>3.26E-10</td>
</tr>
<tr>
<td>Subject 3</td>
<td>3.57E-10</td>
<td>3.98E-10</td>
<td>7.22E-10</td>
<td>6.48E-10</td>
<td>5.15E-10</td>
<td>4.85E-10</td>
<td>5.23E-10</td>
<td>5.50E-10</td>
<td>N/A</td>
<td>5.25E-10</td>
</tr>
<tr>
<td>Subject 4</td>
<td>6.69E-11</td>
<td>4.16E-10</td>
<td>1.23E-09</td>
<td>2.03E-09</td>
<td>4.54E-09</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1.66E-09</td>
</tr>
</tbody>
</table>
Chapter 5: Results & Observation

**Observation for table and figure 5.3b:**

- Subject 1 shows a sudden change in variance at the last minute of the running. The change in variance of subject 1 is large, especially when it is approaching the end of experiment. The variance increases significantly from $6.77 \times 10^{-10}$ to $1.61 \times 10^{-8}$ from the 2\textsuperscript{nd} to the 3\textsuperscript{rd} minute, which is approximately 23 times larger. Subject 1 has stopped the experiment after the 3\textsuperscript{rd} minute due to the fatigue of the lumbar muscle.
- Subject 4 shows consistent increase of variance throughout the experiment, the change in variance is small given that the average and highest of variance are both in the scale of E-09.
- Consistent variances were observed for subject 2 and 3 throughout the experiment.
Table 5.3c (Channel 3 – Running): The variance of amplitude for each minute time frame for four subjects with low back ailments

<table>
<thead>
<tr>
<th>Time (Minutes)</th>
<th>Channel 3 (Left L4 / L5)</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>of variance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.64E-10</td>
<td>2.21E-08</td>
<td>5.84E-10</td>
<td>1.90E-11</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5.64E-09</td>
<td>1.49E-08</td>
<td>7.21E-10</td>
<td>2.04E-10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4.69E-09</td>
<td>1.53E-09</td>
<td>8.59E-10</td>
<td>4.43E-10</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>N/A</td>
<td>2.84E-09</td>
<td>1.04E-09</td>
<td>5.13E-10</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>N/A</td>
<td>7.21E-08</td>
<td>1.03E-09</td>
<td>6.36E-10</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>N/A</td>
<td>1.16E-07</td>
<td>1.15E-09</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>N/A</td>
<td>2.70E-08</td>
<td>7.08E-10</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>N/A</td>
<td>4.12E-07</td>
<td>4.04E-09</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>N/A</td>
<td>7.74E-08</td>
<td>N/A</td>
<td>1.27E-09</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.53E-09</td>
<td></td>
<td>1.27E-09</td>
<td>3.63E-10</td>
</tr>
</tbody>
</table>
**Observation for table and figure 5.3c:**

- Subject 2 has inconsistent variance throughout the experiment, especially after the 5th minute.
- Subject 1, 3 and 4 have very consistent variance throughout the experiment; average variance of three subjects is much smaller compared with subject 2.
- Based on the above observation the change of amplitude in sEMG for subject 2 is very high throughout the experiment, especially when the time of running increases.
Table 5.3d (Channel 4 – Running): The variance of amplitude for each minute time frame for four subjects with low back ailments

<table>
<thead>
<tr>
<th></th>
<th>Time (Minutes)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Channel 4 (Right L4 / L5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 1</td>
<td>3.47E-10</td>
<td>3.97E-06</td>
<td>1.05E-07</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1.36E-06</td>
</tr>
<tr>
<td>Subject 2</td>
<td>8.32E-11</td>
<td>1.84E-10</td>
<td>1.37E-10</td>
<td>2.05E-10</td>
<td>8.51E-10</td>
<td>2.42E-09</td>
<td>1.04E-08</td>
<td>4.18E-08</td>
<td>1.60E-07</td>
<td>2.40E-08</td>
</tr>
<tr>
<td>Subject 3</td>
<td>3.82E-10</td>
<td>3.81E-10</td>
<td>4.64E-10</td>
<td>1.00E-09</td>
<td>2.86E-09</td>
<td>6.16E-10</td>
<td>1.04E-09</td>
<td>1.09E-09</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Subject 4</td>
<td>8.47E-12</td>
<td>3.75E-11</td>
<td>3.81E-11</td>
<td>4.36E-11</td>
<td>4.39E-11</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Chapter 5: Results & Observation

Observation for table and figure 5.3d:
- Subject 1 has a sudden change in variance after the 1st minute, which is very large. The variance of subject 1 at the 2nd minute is $3.97\times10^{-6}$ and it is approximately 38 time larger compared with the variance at the 3rd minute ($1.05\times10^{-7}$).
- Subject 2 has consistent variance from time zero to the 6th minute and the variance starts to increase after the 6th minute.
- Subject 3 and 4 have very consistent variance throughout the experiment.
- The sudden change of variance in subject 1 is most likely the result of interference from the Delsys sEMG recorder system.
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5.3.1b: **Observation summary for table and figure from 5.3a to 5.3d (Running – LBP subjects)**

Large inter-subject variation was observed throughout the experiment, but the timing of increase was not predictable. It can occur at the beginning or towards the end of the experiment. This phenomenon suggests that there are large changes in the amplitude of sEMG during running.

The duration of running experiment varies among different LBP subjects, it depends on their muscle condition and level of pain they can endure. Observation from table 5.3a to 5.3d have clearly showed not all LBP subjects can complete the running experiment. Some subjects can only run for 3 minutes and then stop, it is due to the fatigue or the pain in lumbar area. In all our experiment we did not record the level of pain or fatigue during or after the completion of each experiment, but in our experiment procedure (see chapter 3), we have specifically told the LBP participants to stop the experiment when they cannot endure the pain or fatigue in the lumbar area.
Table 5.4a (Channel 1 – Walking): The variance of amplitude for each minute time frame for nine healthy subjects

<table>
<thead>
<tr>
<th>Channel 1 (Left L1 / L2)</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Subject 1</td>
<td>1.06E-11</td>
<td>1.17E-11</td>
</tr>
<tr>
<td>Subject 2</td>
<td>1.15E-11</td>
<td>1.08E-11</td>
</tr>
<tr>
<td>Subject 4</td>
<td>1.29E-10</td>
<td>1.26E-10</td>
</tr>
<tr>
<td>Subject 5</td>
<td>4.09E-10</td>
<td>4.72E-10</td>
</tr>
<tr>
<td>Subject 6</td>
<td>1.56E-10</td>
<td>1.78E-10</td>
</tr>
<tr>
<td>Subject 7</td>
<td>7.75E-11</td>
<td>7.66E-11</td>
</tr>
<tr>
<td>Subject 8</td>
<td>2.65E-11</td>
<td>2.43E-11</td>
</tr>
<tr>
<td>Subject 9</td>
<td>5.10E-11</td>
<td>1.02E-10</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.4a:

- All subjects have showed consistent variance throughout the walking experiment.
- Subject 5 has higher average variance compared with the other subjects, but the intra-subject variation is small.
### Table 5.4b (Channel 2 – Walking): The variance of amplitude for each minute time frame for nine healthy subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Subject 1</td>
<td>9.99E-12</td>
<td>1.07E-11</td>
</tr>
<tr>
<td>Subject 2</td>
<td>2.71E-11</td>
<td>1.92E-11</td>
</tr>
<tr>
<td>Subject 3</td>
<td>2.74E-11</td>
<td>3.21E-11</td>
</tr>
<tr>
<td>Subject 4</td>
<td>1.45E-10</td>
<td>1.06E-10</td>
</tr>
<tr>
<td>Subject 5</td>
<td>2.75E-10</td>
<td>3.00E-10</td>
</tr>
<tr>
<td>Subject 7</td>
<td>3.91E-10</td>
<td>4.34E-10</td>
</tr>
<tr>
<td>Subject 8</td>
<td>3.03E-11</td>
<td>2.68E-11</td>
</tr>
<tr>
<td>Subject 9</td>
<td>1.64E-11</td>
<td>1.71E-11</td>
</tr>
</tbody>
</table>
Chapter 5: Results & Observation

Observation for table and figure 5.4b:
- All subjects have showed consistent variance throughout the walking experiment.
- Subject 7 has showed an ascending trend of variance throughout the experiment.
## Table 5.4c (Channel 3 – Walking): The variance of amplitude for each minute time frame for nine healthy subjects

<table>
<thead>
<tr>
<th>Channel 3 (Left L4 / L5)</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>7.49E-12</td>
</tr>
<tr>
<td>Subject 2</td>
<td>4.82E-12 4.27E-12 3.83E-12 5.23E-12 9.13E-12 1.11E-11 9.62E-12 9.31E-12 3.53E-11 3.29E-11</td>
<td>1.26E-11</td>
</tr>
<tr>
<td>Subject 4</td>
<td>1.38E-10 1.90E-10 2.07E-10 2.36E-10 1.77E-10 1.89E-10 1.21E-10 1.10E-10 1.03E-10 1.04E-10</td>
<td>1.57E-10</td>
</tr>
<tr>
<td>Subject 5</td>
<td>2.47E-10 2.68E-10 2.61E-10 2.64E-10 3.11E-10 3.03E-10 2.79E-10 2.90E-10 2.91E-10 2.83E-10</td>
<td>2.80E-10</td>
</tr>
<tr>
<td>Subject 6</td>
<td>1.24E-10 1.18E-10 1.04E-10 9.27E-11 8.43E-11 1.00E-10 1.23E-10 1.22E-10 1.06E-10 1.06E-10</td>
<td>1.08E-10</td>
</tr>
<tr>
<td>Subject 7</td>
<td>2.31E-11 2.01E-11 2.54E-11 1.93E-11 1.90E-11 2.38E-11 2.08E-11 2.06E-11 2.12E-11 2.16E-11</td>
<td>2.15E-11</td>
</tr>
<tr>
<td>Subject 9</td>
<td>1.43E-11 2.57E-11 3.74E-11 1.42E-11 1.23E-11 9.11E-12 1.11E-11 2.90E-11 2.09E-11 6.88E-11</td>
<td>2.43E-11</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.4c:
- All subjects have showed consistent variance throughout the walking experiment.
- Subject 4, 5 and 6 has slightly higher variance than all other subjects, the average of variance are 1.57E-10, 2.80E-10 and 1.08E-10. The variance of subject 4 is slightly inconsistent compare with the other subjects.
## Table 5.4d (Channel 4 – Walking): The variance of amplitude for each minute time frame for nine healthy subjects

<table>
<thead>
<tr>
<th>Channel 4 (Right L4 / L5)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>4.23E-11</td>
<td>4.29E-11</td>
<td>4.02E-11</td>
<td>3.82E-11</td>
<td>4.39E-11</td>
<td>5.42E-11</td>
<td>5.64E-11</td>
<td>5.54E-11</td>
<td>N/A</td>
<td>N/A</td>
<td>4.67E-11</td>
</tr>
<tr>
<td>Subject 2</td>
<td>2.64E-11</td>
<td>1.73E-11</td>
<td>1.56E-11</td>
<td>1.80E-11</td>
<td>3.32E-11</td>
<td>6.63E-11</td>
<td>3.87E-11</td>
<td>2.85E-11</td>
<td>8.14E-11</td>
<td>7.08E-11</td>
<td>3.96E-11</td>
</tr>
<tr>
<td>Subject 3</td>
<td>1.49E-11</td>
<td>1.99E-11</td>
<td>1.68E-11</td>
<td>1.58E-11</td>
<td>1.52E-11</td>
<td>1.83E-11</td>
<td>1.94E-11</td>
<td>2.68E-11</td>
<td>2.77E-11</td>
<td>2.76E-11</td>
<td>2.03E-11</td>
</tr>
<tr>
<td>Subject 4</td>
<td>3.67E-10</td>
<td>3.56E-10</td>
<td>3.83E-10</td>
<td>4.55E-10</td>
<td>4.19E-10</td>
<td>5.30E-10</td>
<td>4.29E-10</td>
<td>3.95E-10</td>
<td>3.43E-10</td>
<td>3.31E-10</td>
<td>4.01E-10</td>
</tr>
<tr>
<td>Subject 5</td>
<td>9.44E-11</td>
<td>1.29E-10</td>
<td>1.15E-10</td>
<td>1.07E-10</td>
<td>1.01E-10</td>
<td>1.13E-10</td>
<td>9.66E-11</td>
<td>9.44E-11</td>
<td>9.62E-11</td>
<td>9.85E-11</td>
<td>1.05E-10</td>
</tr>
<tr>
<td>Subject 6</td>
<td>1.89E-10</td>
<td>2.15E-10</td>
<td>1.95E-10</td>
<td>1.78E-10</td>
<td>1.66E-10</td>
<td>1.87E-10</td>
<td>2.19E-10</td>
<td>2.02E-10</td>
<td>1.82E-10</td>
<td>1.80E-10</td>
<td>1.91E-10</td>
</tr>
<tr>
<td>Subject 7</td>
<td>1.39E-11</td>
<td>1.49E-11</td>
<td>2.05E-11</td>
<td>1.54E-11</td>
<td>1.58E-11</td>
<td>3.42E-11</td>
<td>1.62E-11</td>
<td>2.20E-11</td>
<td>1.73E-11</td>
<td>1.84E-11</td>
<td>1.89E-11</td>
</tr>
<tr>
<td>Subject 8</td>
<td>2.00E-10</td>
<td>9.37E-11</td>
<td>1.07E-10</td>
<td>1.15E-10</td>
<td>1.08E-10</td>
<td>1.10E-10</td>
<td>1.05E-10</td>
<td>1.07E-10</td>
<td>1.14E-10</td>
<td>9.12E-11</td>
<td>1.15E-10</td>
</tr>
<tr>
<td>Subject 9</td>
<td>6.18E-12</td>
<td>5.28E-12</td>
<td>4.52E-12</td>
<td>6.65E-12</td>
<td>5.67E-12</td>
<td>4.57E-12</td>
<td>7.77E-12</td>
<td>4.64E-11</td>
<td>4.08E-11</td>
<td>4.08E-11</td>
<td>1.69E-11</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.4d:
- All subjects have showed consistent variance throughout the walking experiment, only subject 4 has slightly higher variance than the others.

5.3.2a: Observation summary for table and figure from 5.4a to 5.4d (Walking – Healthy subjects)
From the table 5.4a to 5.4d, it is observed that variation of inter-subject was very small for a given walking speed. For the same walking speed the change in variance for healthy subjects compare with LBP subjects were very similar, compare table 5.4a – 5.4d with table 5.2a – 5.2d.
Table 5.5a (Channel 1 – Running): The variance of amplitude for each minute time frame for nine healthy subjects

<table>
<thead>
<tr>
<th>Channel 1</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Left L1 / L2)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Subject 1</td>
<td>2.51E-11</td>
<td>2.87E-11</td>
</tr>
<tr>
<td>Subject 2</td>
<td>9.70E-11</td>
<td>1.14E-09</td>
</tr>
<tr>
<td>Subject 3</td>
<td>6.22E-11</td>
<td>6.74E-11</td>
</tr>
<tr>
<td>Subject 4</td>
<td>4.13E-10</td>
<td>4.33E-10</td>
</tr>
<tr>
<td>Subject 5</td>
<td>7.14E-10</td>
<td>5.61E-10</td>
</tr>
<tr>
<td>Subject 6</td>
<td>3.40E-10</td>
<td>4.47E-10</td>
</tr>
<tr>
<td>Subject 7</td>
<td>9.16E-10</td>
<td>1.06E-09</td>
</tr>
<tr>
<td>Subject 8</td>
<td>1.26E-10</td>
<td>2.10E-10</td>
</tr>
<tr>
<td>Subject 9</td>
<td>2.02E-10</td>
<td>2.88E-10</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.5a:

- The variance of all subjects in table 5.5a is higher than the variance of walking in above tables (Between 5.4a to 5.4d).
- The variance of figure 5.5a may appear to be inconsistent, but from the observation in low back ailment group it shows the variances in running are generally higher than walking. Based on this observation the change in variance for subject 2 and 7 are relatively small because it is close to the average variance.
- The range of average variance of running in channel 1 is between 1.71E-10 to 7.52E-10, and they are in the same scale.
Table 5.5b (Channel 2 – Running): The variance of amplitude for each minute time frame for nine healthy subjects

<table>
<thead>
<tr>
<th>Channel 2 (Right L1 / L2)</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>2.07E-10</td>
</tr>
<tr>
<td>Subject 2</td>
<td>1.75E-11 1.82E-11 1.60E-10 2.83E-10 5.58E-10 N/A N/A N/A N/A N/A 2.07E-10</td>
<td></td>
</tr>
<tr>
<td>Subject 3</td>
<td>1.22E-10 1.90E-10 5.41E-10 7.59E-10 1.63E-09 N/A N/A N/A N/A N/A 1.25E-09</td>
<td></td>
</tr>
<tr>
<td>Subject 4</td>
<td>8.14E-11 9.51E-11 1.11E-10 1.33E-10 4.29E-10 3.45E-10 3.24E-10 2.54E-10 2.05E-10 1.83E-10 2.16E-10</td>
<td></td>
</tr>
<tr>
<td>Subject 5</td>
<td>3.35E-10 3.31E-10 3.24E-10 3.40E-10 2.72E-10 1.58E-10 1.36E-10 9.46E-11 7.77E-11 7.79E-11 2.15E-10</td>
<td></td>
</tr>
<tr>
<td>Subject 6</td>
<td>7.37E-10 7.49E-10 5.73E-10 6.50E-10 5.60E-10 5.99E-10 5.88E-10 7.50E-10 6.75E-10 6.35E-10 6.52E-10</td>
<td></td>
</tr>
<tr>
<td>Subject 7</td>
<td>1.91E-10 2.15E-10 2.50E-10 3.27E-10 4.02E-10 3.29E-10 3.32E-10 3.31E-10 3.08E-10 2.90E-10 2.97E-10</td>
<td></td>
</tr>
<tr>
<td>Subject 8</td>
<td>4.96E-09 5.46E-09 5.68E-09 3.90E-09 3.60E-09 2.43E-09 1.46E-09 1.09E-09 1.05E-09 1.01E-09 3.07E-09</td>
<td></td>
</tr>
<tr>
<td>Subject 9</td>
<td>1.25E-10 2.47E-10 1.27E-10 1.24E-10 1.12E-10 1.99E-10 2.97E-10 2.79E-10 2.63E-10 2.64E-10 2.04E-10</td>
<td></td>
</tr>
<tr>
<td>Subject 10</td>
<td>7.20E-11 7.99E-11 6.41E-11 4.18E-10 1.39E-10 1.14E-08 N/A N/A N/A N/A 2.02E-09</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 5: Results & Observation

Observation for table and figure 5.5b:

- Except Subject 7 & 9 all other subjects in channel 2 were observed to have consistent variance throughout the experiment.
- Subject 7 had slightly higher variance than the other subjects; it suggested that there may be a higher variation of amplitude from the start to 5\textsuperscript{th} minute and the variation become stable after 5\textsuperscript{th} minute.
- Subject 9 was observed a sudden change in variance at the last minute; it increases from 1.39E-10 to 1.14E-08.
- The range of average variance of running in channel 2 is between 2.04E-10 to 3.07E-09. Apart from the sudden change of variance in subject 9, the above observation suggested that variance of amplitude is constrained.
Table 5.5c (Channel 3 – Running): The variance of amplitude for each minute time frame for nine healthy subjects

<table>
<thead>
<tr>
<th>Channel 3 (Left L4 / L5)</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Subject 1</td>
<td>8.91E-12</td>
<td>7.91E-12</td>
</tr>
<tr>
<td>Subject 2</td>
<td>4.99E-11</td>
<td>6.02E-10</td>
</tr>
<tr>
<td>Subject 3</td>
<td>3.47E-10</td>
<td>5.33E-10</td>
</tr>
<tr>
<td>Subject 4</td>
<td>1.00E-09</td>
<td>5.79E-10</td>
</tr>
<tr>
<td>Subject 5</td>
<td>7.95E-10</td>
<td>7.03E-10</td>
</tr>
<tr>
<td>Subject 6</td>
<td>2.38E-10</td>
<td>2.73E-10</td>
</tr>
<tr>
<td>Subject 7</td>
<td>2.99E-09</td>
<td>7.58E-10</td>
</tr>
<tr>
<td>Subject 8</td>
<td>3.01E-10</td>
<td>3.53E-10</td>
</tr>
<tr>
<td>Subject 9</td>
<td>1.76E-10</td>
<td>3.25E-10</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.5c:

- Subject 4 and 7 has higher variance than the others, especially toward the end of experiment. The highest variance of subject 4 and 7 is 1.96E-08 and 2.35E-08 at the 9th minute.
- Except subject 4 and 7, all other subjects in channel 3 were observed to be consistent variance throughout the experiment.
- The range of average variance of running in channel 3 is between 2.51E-11 to 7.77E-09. Apart from the large increase of variance for the subject 4 and 7, the above observation suggested that variance of amplitude is constrained.
### Table 5.5d (Channel 4 – Running): The variance of amplitude for each minute time frame for nine healthy subjects

<table>
<thead>
<tr>
<th>Channel 4 (Right L4 / L5)</th>
<th>Time (Minutes)</th>
<th>Average of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>5.24E-11</td>
<td>5.06E-11</td>
</tr>
<tr>
<td>Subject 2</td>
<td>9.64E-11</td>
<td>2.49E-10</td>
</tr>
<tr>
<td>Subject 3</td>
<td>7.19E-11</td>
<td>7.72E-11</td>
</tr>
<tr>
<td>Subject 4</td>
<td>1.85E-09</td>
<td>8.64E-10</td>
</tr>
<tr>
<td>Subject 5</td>
<td>5.42E-10</td>
<td>3.64E-10</td>
</tr>
<tr>
<td>Subject 6</td>
<td>4.23E-10</td>
<td>4.47E-10</td>
</tr>
<tr>
<td>Subject 7</td>
<td>1.70E-10</td>
<td>1.35E-10</td>
</tr>
<tr>
<td>Subject 8</td>
<td>7.77E-10</td>
<td>8.62E-10</td>
</tr>
<tr>
<td>Subject 9</td>
<td>8.63E-12</td>
<td>1.63E-11</td>
</tr>
</tbody>
</table>
Observation for table and figure 5.5d:

- Except subject 1 all other subjects were observed to be consistent variance throughout the experiment.
- There is a sudden change in variance at the last minute of subject 1, it increase from 3.50E-10 to 2.05E-09.
- The range of average variance of running in channel 4 is between 4.51E-11 to 6.55E-10. Apart from the sudden change of variance in subject 1, the above observation suggested that variance of amplitude is constrained.
- Based on the above observation in walking and running (From table and figure 5.4a to 5.5d), it is clearly observed that the rate of increase in variance is higher in running when compared with walking.
5.3.2b: Observation summary for table and figure from 5.5a to 5.5d (Running – Healthy subjects)

- The inter-subject variation is small for most of the healthy subjects, although there were a few inconsistent variances especially toward the end of running. The variance increase systematically with the increase of speed, this suggested that more muscle was involved during running when compared with walking.
- The intra-subject variation is much smaller compared with LBP subjects, this suggested LBP patients required more muscle in running. But the number of muscle involved during running was base on the muscle strength, it mean LBP patient may have weaker muscle. This phenomenon suggested that the change in speed have influenced the amplitude patterns of sEMG, but the overall pattern may remain very much unchanged.
Chapter 5: Results & Observation

5.3.3: Summary of comparison of all channels in average variance between both healthy and low back ailment subjects

Table 5.6a (All 4 Channels): The average variance of amplitude for both healthy & low back ailment subject during walking experiment

<table>
<thead>
<tr>
<th></th>
<th>Healthy Subjects</th>
<th>Unhealthy Subjects (LBP patient)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Channel 1</td>
<td>Channel 2</td>
</tr>
<tr>
<td>1</td>
<td>1.83E-11</td>
<td>1.34E-11</td>
</tr>
<tr>
<td>2</td>
<td>2.84E-11</td>
<td>4.43E-11</td>
</tr>
<tr>
<td>3</td>
<td>3.98E-11</td>
<td>2.68E-11</td>
</tr>
<tr>
<td>4</td>
<td>1.31E-10</td>
<td>1.24E-10</td>
</tr>
<tr>
<td>5</td>
<td>4.47E-10</td>
<td>2.61E-10</td>
</tr>
<tr>
<td>6</td>
<td>1.78E-10</td>
<td>9.08E-11</td>
</tr>
<tr>
<td>7</td>
<td>1.02E-10</td>
<td>5.35E-10</td>
</tr>
<tr>
<td>8</td>
<td>2.29E-11</td>
<td>2.56E-11</td>
</tr>
<tr>
<td>9</td>
<td>5.46E-11</td>
<td>3.45E-11</td>
</tr>
</tbody>
</table>

Mean

<table>
<thead>
<tr>
<th></th>
<th>Healthy Subjects</th>
<th>Unhealthy Subjects (LBP patient)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Channel 1</td>
<td>Channel 2</td>
</tr>
<tr>
<td>Mean</td>
<td>1.13556E-10</td>
<td>1.28378E-10</td>
</tr>
</tbody>
</table>

Observation for Table 5.6a:
- Healthy subjects were observed to have smaller variation in variance for all four channels during walking experiment.
- The average variance of low back pain subjects from channel 1 to 3 were observed in a very similar range when compared to the healthy subjects, but in channel 4 the average variance is much higher than healthy subjects.
### Table 5.6b (All 4 Channels): The average variance of amplitude for both healthy & low back ailment subject during running experiment

<table>
<thead>
<tr>
<th></th>
<th>Healthy Subjects</th>
<th>Unhealthy Subjects (LBP patient)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Channel 1</td>
<td>Channel 2</td>
</tr>
<tr>
<td>1</td>
<td>1.97E-10</td>
<td>2.07E-10</td>
</tr>
<tr>
<td>2</td>
<td>7.52E-10</td>
<td>1.25E-09</td>
</tr>
<tr>
<td>3</td>
<td>1.71E-10</td>
<td>2.16E-10</td>
</tr>
<tr>
<td>4</td>
<td>4.51E-10</td>
<td>2.15E-10</td>
</tr>
<tr>
<td>5</td>
<td>6.84E-10</td>
<td>6.52E-10</td>
</tr>
<tr>
<td>6</td>
<td>5.10E-10</td>
<td>2.97E-10</td>
</tr>
<tr>
<td>7</td>
<td>6.48E-10</td>
<td>3.07E-09</td>
</tr>
<tr>
<td>8</td>
<td>1.74E-10</td>
<td>2.04E-10</td>
</tr>
<tr>
<td>9</td>
<td>3.57E-10</td>
<td>2.02E-09</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Channel 1</td>
<td>Channel 2</td>
</tr>
<tr>
<td></td>
<td>1.21E-09</td>
<td>2.05E-09</td>
</tr>
</tbody>
</table>

**Observation for Table 5.6b:**
- The average variance in all channels for both healthy and LBP subjects were observed to have a significant increase compared with the walking experiment. The intra-subject variation of healthy subjects is smaller in all cases compare with LBP subjects.
- LBP subjects were observed to have larger variation within the subjects and between difference LBP subjects.
- Larger variation were observed in the above tables for LBP subjects (table 5.6a to 5.6b), it suggested that people with LBP ailment a more likely to have significant changes in amplitude for both walking and running experiment. The change in amplitude appears to be more frequently during faster dynamic locomotion such as running.
5.4: Observations

5.4.1: Activation period analyzing method

Observations from table 5.1a and 5.1b:

The activation period for all the subjects, recorded while they are walking at the same speed, is similar for the subjects and this does not appear to change significantly between the LBP and healthy subjects. In all channels and all cases, the standard deviation is less than 10% for within the group and 18% is the maximum difference between the two groups.

The result of change in speed of walking had comparable change in the activation period. Reduction in the speed of walking from 4.5 Km/ hour to 2.25 km/ hour resulted in the activation period increase by 50%, and the standard deviation increased.

5.4.2: Amplitude analyzing method

5.4.2a: Subjects with Low Back Ailments (Walking)

Observation from Table 5.2a to d: The walking experiment

The inter-subject variation in the amplitude of recorded sEMG during walking was low in most subjects for all channels. Observation from table and figure 5.2a to 5.2d shows nearly straight line of variance in subject 1, 2 and 4 for all channels. Subject 3 has slightly higher variance in all channels, and it is not as consistent as the others. There is a sudden change in variance of subject 3 in channel 4; it is most likely related to the artifact signal from the Delsys recording system. Overall the variance of subject 3 is relatively consistent given that the range of variance is always within E-10, which is very similar to the other subjects in the same condition.

The intra-subject variation was higher compared with inter-subject variation in all channels of walking. This phenomenon suggested each subject have slightly difference sEMG during the same locomotion such as walking, but within each subject the sEMG signal have behaved in a similar way.

5.4.2b: Subjects with Low Back Ailments (Running)

Observation from table and figure 5.3a to 5.3d

Large inter-subject variation was observed throughout the experiment and this was not based on whether the recordings were related to the start or the end of the experiment. This phenomenon suggested that there were large changes in the strength of sEMG during running.

The intra-subject variation is much higher during running compared with walking. The duration of running experiment varied between different LBP subjects. In general, healthy back
individuals were able to run for longer periods compared with the subjects with LBP. This may suggest that there is inherent weakness of the lumbar muscle in LBP subjects.

5.4.3: The healthy subjects (Walking and Running)

Observation from table and figure 5.4(a-d) to 5.5(a-d)

From tables and figures 5.4(a-d) to 5.5(a-d), it is observed that there is low inter-subject variation for a given speed of walking of the subjects. It is also observed that the variation for the duration of the experiment appears to be based on the speed of walking of the subjects. The results also indicate that this variation is greater when the speed of walking / running increases. A small change in this variation is observed near the end of the experiments.

Based on the comparison with tables and figures 5.4(a-d) to 5.5(a-d), it is observed that the inter-subject variation is much smaller for healthy subjects compared with LBP subjects.
Chapter 5: Results & Observation

5.5: Summary of Key findings
Table 5.7: Summary of key findings

<table>
<thead>
<tr>
<th>Subjects condition</th>
<th>Type of experiment</th>
<th>Placement of electrode</th>
<th>Brief observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBP (Low Back Pain)</td>
<td>Walking</td>
<td>Channel 1 (Left L1 / L2)</td>
<td>Small variance in amplitude (E-11 ≤ Variance ≤ E-08) Amplitude constrained.</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 2 (Right L1 / L2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 3 (Left L4 / L5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 4 (Right L4 / L5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 1 (Left L1 / L2)</td>
<td>Increase in variance compare to walking. (E-11 ≤ Variance ≤ E-06 )</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 2 (Right L1 / L2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 3 (Left L4 / L5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 4 (Right L4 / L5)</td>
<td></td>
</tr>
<tr>
<td>Healthy</td>
<td>Walking</td>
<td>Channel 1 (Left L1 / L2)</td>
<td>Small variance in amplitude (E-12 ≤ Variance ≤ E-10) Amplitude constrained.</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 2 (Right L1 / L2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 3 (Left L4 / L5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>Channel 4 (Right L4 / L5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 1 (Left L1 / L2)</td>
<td>Increase in variance compare to walking. (E-11 ≤ Variance ≤ E-09 )</td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 2 (Right L1 / L2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 3 (Left L4 / L5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Running</td>
<td>Channel 4 (Right L4 / L5)</td>
<td></td>
</tr>
</tbody>
</table>
### Summary of key findings (Continue)

<table>
<thead>
<tr>
<th>Comparison between Healthy &amp; LBP subjects for all channels</th>
<th>Walking</th>
<th>All Channels</th>
<th>Healthy VS LBP subjects</th>
<th>Running</th>
<th>All Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy VS LBP subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The variations between Healthy &amp; LBP subjects are minimal.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Healthy VS LBP subjects</td>
<td></td>
<td></td>
<td>The variance of LBP subjects is much higher when compared to healthy subjects, especially towards the end of the experiment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chapter 6: Discussion and Conclusion

This thesis reports research undertaken to identify the differences between muscle activity of the lumbar back muscles for people with healthy backs and people suffering with low back pain (LBP) when they were walking and running. The data analysis can be broadly divided into two; (i) activation period analysis and (ii) amplitude of sEMG analysis. The outcomes of the experiments for the two have been discussed separately in the following sections.

6.1: Discussions:

The above observations suggest that there are large variations among the LBP cohort may be explained on the basis that there may be variations taking place in the activation strategies of the people with LBP while people with healthy backs performed the cyclic tasks more consistently and their muscles did not require a change in the activation strategy. This may suggest that there is inherent weakness of the lumbar muscles related to gait of the LBP. This is also supported based on the inability of the LBP subjects to run for the requested 10 minutes. The difference between the walking and running may be attributable to the phasic tonic muscle fibres, with phasic fibres relevant to running compared with tonic responsible for walking. Based on the observations, it is suggested that duration between each gait cycle activity should be relatively constant for healthy and LBP subjects under low walking speed.

From table 5.2d, it was observed that the strength of sEMG remained largely unchanged from the start to the end of the walking exercise for all but one healthy subject (subject 1). This suggests that there was no onset of fatigue among these subjects and is consistent with the expectations. Most healthy people walk for longer than 10 minutes and do not get fatigued in this relatively short duration of time. An obvious artifact in subject 3, 5th minute segment was ignored.

It was also observed that there was an increase of variance during running. This may be attributable to:

1) In general, the participants were used to walking but not used to running. This would suggest that when they began to run, they consistently varied their muscle activation/deactivation strategies. Also, the levels of contraction during running was much larger than during walking resulting in larger cyclic activity and thus larger variance in the magnitude of sEMG.
Chapter 6 Discussion and Conclusion

2) The higher variance among the LBP cohort suggests that while the healthy back group may not be trained athletes, this group were less prepared for running and varied their activation more often. This can also be explained based on the muscles being fatigued which would result in larger number of motor units getting activated resulting in larger cyclic changes and thus larger variance.

3) Not all the LBP subjects were able to finish the whole running experiment. This further suggested the lack of preparedness of the LBP group to run and for their muscles to fatigue quickly.

6.1.1: Discussions of others literature that have similar findings

The significant difference between the two cohorts observed during running is attributable to the early onset of muscle fatigue in the LBP cohort. While there is an increase in the variance for both the groups, the onset of fatigue in the LBP patients would be significantly faster and greater, resulting in these participants altering their activation strategy over the duration of the exercise. The alteration in activation strategy would cause a large change in the variance in the LBP cohort compared with the healthy participants. This would confirm the earlier findings of Lee C and others that LBP patients fatigue more than the healthy participants (Lee C et al…1995). Due to the onset of muscle fatigue, the participants changed their muscle activation strategy.

The results also confirm the findings of earlier researchers Lee C that L4 and L5 is the most suitable location of electrodes for identifying the difference in the LBP compared with the healthy participants (Lee C et al…1995). From these results, it is concluded that variance and change of variance over time of sEMG recorded from L4/ L5 region during running may be used to identify the LBP patients.
6.2: Conclusion

Based on the data obtained, it has been concluded that there is a measurable difference between the sEMG of people with healthy back and people suffering LBP when they are running. Based on the findings, the concepts underlying these observed differences have been postulated. These can be considered in two categories; variations and consistencies in the activation patterns of healthy back subjects and for people with LBP. These have been developed based on the interpretation of experimental data. The postulates along with the supporting data are provided below.

6.2.1: Pattern of the healthy subjects

For healthy subjects, the variance of the muscle activity was observed to be relatively constant under constant walking speed. The increase in the variance appears to be related to the level of activity, and this is observed from the plot between the level of variance of the activity and the duration (figure 6.2a). From this conceptual diagram, it can be postulated that: 1) the strength of the lumbar muscle will determine the duration (D) during which the variance remains consistent; the stronger muscle contraction will give relatively constant variance for a longer period of time. 2) After certain segment of time there will be an increase in variance which may be due to the onset of muscle fatigue. It will be related to the change of muscle activation strategy (MAS). 3) The pattern of the healthy subjects should have monotonic relationship between variance (H) and duration (D).
Figure 6.2a: The conceptual diagram of the pattern of healthy subjects during constant speed of walking.

D - The duration of consistent variance is depended on the strength of the lumbar muscle
H - The change in variance is proportional to the change of Peak Amplitude
Original - The group of muscles have been activate since the beginning of the walking
Extra - Extra muscles have recruited
Chapter 6 Discussion and Conclusion

6.2.2: Pattern of the LBP subjects

From the outcomes of the experiments and the resultant conceptual plot, it is observed that in the early stages, there is similarity between the LBP and healthy back subjects, with the variance remaining unchanged. After this early similarity between the two cohorts, the differences appear and the variance in the amplitude of the LBP subjects begins to vary widely. This may be attributable to inconsistent MAS which is a result of reaction to fatigue rather than according to a recruitment strategy. A resultant observable outcome if that the variance for LBP subjects is nonsystematic. While this relationship between D and H appears to be monotonic, and variance appears related to the strength of muscle and duration, the graph appears to be having large band of uncertainty compared with healthy back subjects.

Figure 6.2b: The conceptual diagram of the pattern of LBP subjects during constant speed of walking.

Original - The group of muscles have been activate since the beginning of the walking
Extra - Extra muscles have recruited
Chapter 6 Discussion and Conclusion

6.2.3: The comparison of the healthy and LBP subjects

From the conceptual diagram, it can be suggested that: 1) In a constant speed condition the amplitude of the sEMG will remain relatively constant before the change of MAS at the lumbar area for both subject groups. 2) The rate of change in MAS will depend on muscle condition of the lower trunk; based on the assumption that healthy people have the stronger trunk muscle than people with low back ailment patient. 3) After certain period of time there will be an increase in variance for both groups. The rate of change should appear higher and faster for LBP patient than healthy people. 4)

Figure 6.2c: The conceptual diagram of the comparison between Healthy and LBP subject.

\[\text{Figure 6.2c: The conceptual diagram of the comparison between Healthy and LBP subject.}\]

\[\text{Comparison between Healthy Subject and LBP Subject}\]

\[\text{Figure 6.2c: The conceptual diagram of the comparison between Healthy and LBP subject.}\]

\[\text{Variance of Amplitude}\]

\[\text{Walking at constant speed of 4.5 km/hour}\]

\[\text{Time}\]

\[\text{D - The duration of consistent variance is depended on the strength of the lumbar muscle}\]

\[\text{H - The change in variance is proportional to the change of Peak Amplitude}\]

\[\text{Original - The group of muscles have been activate since the begining of the walking}\]

\[\text{Extra - Extra muscles have recruited}\]

One common observation for the experiments conducted appear that while there is a consistency between the variance, strength of muscle activity and duration fort healthy subjects, there appears to be less defined relationship for the LBP cohort. There appears to be greater amount of unpredictability for the LBP subjects.
Chapter 6 Discussion and Conclusion

6.3: **Recommendation**

This study has demonstrated that sEMG during walking demonstrates measurable differences between the LBP and healthy back cohorts and may be used to separate the two groups. At this stage, it is not clear if this can be used for identifying low back ailments prior to the onset of pain the lower back. This would be extremely useful because it would provide a promise for non-invasive identification of people who may be at a risk of low back ailments and thus clinicians could do the needful to mitigate the risks and thus reduce the chances of the person suffering from LBP episodes.

The other important study that would help take this work to helping the general population is to have a larger patients group and from wider demographics such that differences in age, gender and general fitness can also be taken into account.
References


Reference


Hodges P W, Richardson C A, 1997. “Feed forward contraction of the transversus abdominis is not influenced by the direction of arm movement”  *Journal of Exp Brain Res* no 114, pp 362–70


Reference


Kumar K D, 2007, Classifiers, course reading form EEET1415, RMIT University, Melbourne, viewed 22 December 2006, RMIT University Library.


Reference


Appendix A: Matlab Code for EMG Normalization and Filtering
This set the data start from Zero.

clear;

% Using the loademg3 to read the data from the Delsys system.
[header, data]=loademg3('Test[Rep1].emg');

% This following codes allow you to separate the channel from 1 to N.
% \( W_{1\_ch\_1} \) is mean Walking 1'st Minutes in channel one, same as the others.
% \( R_{1\_ch\_1} \) is mean Running 1'st Minutes in channel one, same as the others.

N=4; %N is the number of channels
walk = data';
for order=1:1:N
    eval(['W_{1\_ch\_}',num2str(order), ' = walk(:,',num2str(order),',');']);
end

% The detrend function normalize the amplitude of raw EMG data to start zero.
for order=1:1:N
    eval(['W_{1\_ch\_}',num2str(order), ' = detrend(W_{1\_ch\_}',num2str(order),',');']);
end

% Calculate the frequency of each channels for filtering purposes.
% The bandwidth of SEMG signals are normally between 20 Hz to 200 Hz.
% Peridogram is use to calculate power spectral density of the signal,
% rectwin--The window size, the lenght of the nfft, the sample frequency(fs),
% and finally the f--frequency range it depended on the nfft and fs.
WinSize = 60000; fs = 1000;
for order=1:1:N
    eval(['[Px',num2str(order),',f] = periodogram(W_{1\_ch\_}',num2str(order),',rectwin(',WinSize),',1024*1024,fs);']);
end

% Plot the peridogram of all channels and identify any noise or artifact
% signals for filitering.
for p=1:1:N
    eval(['figure(1',num2str(p),',');']);
    subplot(211);
    eval(['plot(f,Px',num2str(p),');']); xlabel('Frequency'); ylabel('Density'); title('PSD Original'); grid on
    set(gca,'YLim',[0 9e-11]); %set the Y_axes to this limt, it use the same way when setting the X_axes.
    subplot(212)
    eval(['plot(f,log(Px',num2str(p),');')); xlabel('Frequency'); ylabel('Density'); title('PSD Original'); grid on
end

% Noise and signal interference filtering.
for CH=1:1:N
    eval(['x = W_{1\_ch\_}',num2str(CH),',');]);
% The Notch filter will able to filt out any specific frequency from the input signal.
% The number of notch filter require will depended on the noise and interference.
% To increase the sharpness of the cutoff frequency by decrease the value of bw.
wo = 50/(1000/2);  bw = wo/1000/0.05;
[b,a] = iirnotch(wo,bw);
Filter_50 = filter(b, a, x);
for hz=100:100:400
    wo = hz/(1000/2);  bw = wo/1000/0.05;
    [b,a] = iirnotch(wo,bw);
    Filter_50 = filter(b, a, Filter_50);
end

% The Bandpass filter will cut off all the high frequency signal.
% The cut off frequency will normal between 15 to 150hz, but in our cause we start at 1hz to minimize the data loss of the raw EMG.
% The order of filter is 6 order.
w1 = 1/(1000/2); w2 = 150/(1000/2); f_order=6;
Wn=[w1 w2];
[b,a]=butter(f_order,Wn,'bandpass');
eval(['Filter_b', num2str(CH), ' = filter(b,a,Filter_50);']);
end

% Check the raw EMG signal after filtering and identify if there is any major data loss. If yes change the cutoff frequency of the notch or bandpass filter.
WinSize = 60000; fs = 1000;
for order=1:1:N
    eval(['[Pb',num2str(order),',f] = periodogram(Filter_b',num2str(order), ',',num2str(rectwin(WinSize)),1024*1024,fs);']);
end
for p=1:1:N
    eval(['figure(2',num2str(p),')']);
    subplot(211);
    eval(['plot(f,Pb',num2str(p),');']); xlabel('Frequency'); ylabel('Density'); title('PSD Original'); grid on
    set(gca, 'YLim', [0 9e-11]); %set the Y_axes to this limt, it use the same way when setting the X_axes.
    subplot(212)
    eval(['plot(f,log(Pb',num2str(p),'));']); xlabel('Frequency'); ylabel('Density'); title('PSD Original'); grid on
Appendix B: Matlab Code for Activation Analysis Method
% MatLab Analysis Part 1a (Activation Analysis)

% In order to calculate the activation period of the sEMG signal two parts
% need to be calculate: 1) The threshold of the average EMG, 2) The RMS
% (Root Mean Square) of the EMG. This is the continuous from the Part 1.

%---- 1) Threshold calculation ----%
% Calculate the rms value of the signal, set the window size = 1, this will
% minimize the amount of data loss and increase the accuracy of activation
% period detection.
R_WinSize = 1; O_L_Percent = 0;
for order=1:1:N
    eval(['W_1_ch_',num2str(order), 'rms_s = rrms(Filter_b',num2str(order),',',num2str(R_WinSize),',',num2str(O_L_Percent),');']);
end

% Now Sort the EMG signal in the ascent order, P is the percentage of data.
% P in our case should be between 0.8 < P < 0.9, because most of the data
% have very similar amplitude from the start up to 80% or 90%.
% The threshold of the EMG signal is the: average amplitude of the signal
% from the start to 90%. The average value will store in Ave_(CH)rms
P = 0.9;
for CH=1:1:N
    eval(['W_1_ch_',num2str(CH), 'rms_sort = sort(W_1_ch_',num2str(CH),')]);
    % Mean - Calculate the average value of the vector, Round - use to round off the
    % value of the floating into integer.
    eval(['Ave_',num2str(CH), 'rms = mean(W_1_ch_',num2str(CH),')']);
end

%---- 2) RMS calculation ----%
% Calculate the RMS of the filtered EMG signals.
R_WinSize = 5; O_L_Percent = 0;
for order=1:1:N
    eval(['W_1_ch_',num2str(order), 'rms = rrms(Filter_b',num2str(order),',',num2str(R_WinSize),',',num2str(O_L_Percent),');']);
end

% Plot the RMS of the signal and superimpose the threshold into the same plot
% to determine the activation state
figure(30)
subplot(211);
hold on; box on;
plot(W_1_ch_1rms);grid on
plot(Ave_1rms*ones(size(W_1_ch_1rms_s)), 'r');
subplot(212);
hold on; box on;
plot(W_1_ch_2rms);grid on
plot(Ave_2rms*ones(size(W_1_ch_2rms_s)), 'r');
figure(31)
subplot(211);
hold on; box on;
plot(W_1_ch_3rms);grid on
plot(Ave_3rms*ones(size(W_1_ch_3rms_s)),'r');
subplot(212);
hold on; box on;
plot(W_1_ch_4rms);grid on
plot(Ave_4rms*ones(size(W_1_ch_4rms_s)),'r');

% At this state the method to identify the activation period is still
% manually, for the future improvement an automatic detection algorithm
% should be use.
Appendix C: Matlab Code for Amplitude Analysis Method
% MatLab Analysis Part 1a (Amplitude Analysis)

% Compare the amplitude of each gait cycle for the experiment. The total
% number of minutes of each experiment will vary depended on the subjects,
% normally healthy subjects will completed the experiment which is 20
% minutes. For the LBP subjects they may not able to complete the whole
% experiment so the time may be shorter for them.
% This set the data start from Zero;

clear;

Test_1 = 'Test[Rep1].emg';
Test_2 = 'Test[Rep2].emg';
Test_3 = 'Test[Rep3].emg';
Test_4 = 'Test[Rep4].emg';
Test_5 = 'Test[Rep5].emg';
Test_6 = 'Test[Rep6].emg';
Test_7 = 'Test[Rep7].emg';
Test_8 = 'Test[Rep8].emg';
Test_9 = 'Test[Rep9].emg';
Test_10 = 'Test[Rep10].emg';
Test_11 = 'Test[Rep11].emg';
Test_12 = 'Test[Rep12].emg';
Test_13 = 'Test[Rep13].emg';
Test_14 = 'Test[Rep14].emg';
Test_15 = 'Test[Rep15].emg';
Test_16 = 'Test[Rep16].emg';

% Using the loademg3 to read the data from the Delsys system.
for minutes=1:1:16
    eval(['[header, data]=loademg3(Test_',num2str(minutes),',',');']);
end

% The following codes allow you to separate the channel from 1 to N.
% W_1_ch_1 is mean Walking 1’st Minutes in channel one, same as the others.
% R_1_ch_1 is mean Running 1’st Minutes in channel one, same as the others.
N=4; %N is number of channels
walk = data';
for order=1:1:N
    eval(['W_',num2str(minutes),'_ch_',num2str(order),'] = walk(:,',num2str(order),'');']);
end

% The detrend function normalize the amplitude of raw EMG data to start zero.
for order=1:1:N
    eval(['W_',num2str(minutes),'_ch_',num2str(order),'] = detrend(W_',num2str(order),');']);
end

for CH=1:1:N
    eval(['x = W_',num2str(minutes),'_ch_',num2str(CH),';']);
end

% The Notch filter will able to filt out any specific frequency from
% the input signal. The number of notch filter require will depended
% on the noise and interference.To increase the sharpness of the
% cutoff frequency by decrease the value of bw.
wo = 50/(1000/2); bw = wo/1000/0.05;
[b,a] = iirnotch(wo,bw);
Filter_50 = filter(b, a, x);
for hz=100:100:400
    wo = hz/(1000/2); bw = wo/1000/0.05;
    [b,a] = iirnotch(wo,bw);
    Filter_51 = filter(b, a, Filter_50);
end

% This Notch filter filt out the 500 Hz of the Input signal.
wo = 499.9/(1000/2); bw = wo/1000/0.05;
[b,a] = iirnotch(wo,bw);
Filter_5 = filter(b, a, Filter_51);

% The Bandpass filter will cut off all the high frequency signal.
% The the cut off frequency will normal between 15 to 150hz, but in
% our cause we start at 1hz to minimize the data loss of the raw EMG.
% The order of filter is 6 order.
w1 = 1/(1000/2); w2 = 150/(1000/2); f_order=6;
Wn=[w1 w2];
[b,a]=butter(f_order,Wn, 'bandpass');
eval(['W_','num2str(minutes),'_ch_', num2str(CH), ' = filter(b,a,Filter_5);']);

% Sort the sEMG signal in the acsending order.
for CH=1:1:N
    eval(['W_','num2str(minutes),'_ch_',num2str(CH),'_sort = sort(W_','num2str(minutes),'_ch_',num2str(CH),');']);
end

% Calculate the Variance of the signal in different channel along the experiment.
for CH=1:1:N
    eval(['W_','num2str(minutes),'_ch_',num2str(CH),'_var = var(W_','num2str(minutes),'_ch_',num2str(CH),'_sort);']);
end

% Store the value of Variance for each Channel into an array.
eval(['W_all_ch_1 = [', 'num2str(W_1_ch_1var), ', 'num2str(W_2_ch_1var), ', num2str(W_3_ch_1var), ', 'num2str(W_4_ch_1var), ', 'num2str(W_5_ch_1var), ', 'num2str(W_6_ch_1var), ', 'num2str(W_7_ch_1var), ', num2str(W_8_ch_1var), ', num2str(W_9_ch_1var), ', num2str(W_10_ch_1var), ', num2str(W_11_ch_1var), ', num2str(W_12_ch_1var), ', num2str(W_13_ch_1var), ', num2str(W_14_ch_1var), ', num2str(W_15_ch_1var), ', 'num2str(W_16_ch_1var), ']');
eval(['W_all_ch_2 = [', 'num2str(W_1_ch_2var), ', 'num2str(W_2_ch_2var), ', num2str(W_3_ch_2var), ', num2str(W_4_ch_2var), ', num2str(W_5_ch_2var), ', num2str(W_6_ch_2var), ', num2str(W_7_ch_2var), ', num2str(W_8_ch_2var), ', num2str(W_9_ch_2var), ', num2str(W_10_ch_2var), ', num2str(W_11_ch_2var), ', num2str(W_12_ch_2var), ', num2str(W_13_ch_2var), ', num2str(W_14_ch_2var), ', num2str(W_15_ch_2var), ', 'num2str(W_16_ch_2var), ']');
eval(['W_all_ch_3 = [', 'num2str(W_1_ch_3var), ', 'num2str(W_2_ch_3var), ', num2str(W_3_ch_3var), ', num2str(W_4_ch_3var), ', num2str(W_5_ch_3var), ', num2str(W_6_ch_3var), ', num2str(W_7_ch_3var), ', num2str(W_8_ch_3var), ', num2str(W_9_ch_3var), ', num2str(W_10_ch_3var), ', num2str(W_11_ch_3var), ', num2str(W_12_ch_3var), ', num2str(W_13_ch_3var), ', num2str(W_14_ch_3var), ', num2str(W_15_ch_3var), ', num2str(W_16_ch_3var), ']');
(W_15_ch_3var)', '], num2str(W_16_ch_3var), ']);

eval(['W_all_ch_4 = [', num2str(W_1_ch_4var), ' ', num2str(W_2_ch_4var), ' ', num2str(W_3_ch_4var), ' ', num2str(W_4_ch_4var), ' ', num2str(W_5_ch_4var), ' ', num2str(W_6_ch_4var), ' ', num2str(W_7_ch_4var), ' ', num2str(W_8_ch_4var), ' ', num2str(W_9_ch_4var), ' ', num2str(W_10_ch_4var), ' ', num2str(W_11_ch_4var), ' ', num2str(W_12_ch_4var), ' ', num2str(W_13_ch_4var), ' ', num2str(W_14_ch_4var), ' ', num2str(W_15_ch_4var), ' ', num2str(W_16_ch_4var), ']');

% The solid line representing the Walking part of the experiment.
blue='b'; green='g'; red='r'; cyan='c'; magenta='m'; yellow='y'; black='k';
% The dash-line representing the running part of the experiment.
xblue='--b'; xgreen='--g'; xred='--r'; xcyan='--c'; xmagenta='--m'; xyellow='--y'; xblack='--k';

% Plot the sort of Amplitude for each minutes and superimpose them into the
% same plot for comparison.
for p=1:1:N
    eval(['figure(1',num2str(p),')']);
    hold on; box on;
    set(gca, 'YLim', [-9e-5 9e-5]); %set the Y_axes to this limit, it use the same way
    when setting the X_axes.
    eval(['plot(W_1_ch_',num2str(p),', sort, blue);']); xlabel('Order'); ylabel('Amplitude'); title('EMG Sort'); grid on
    eval(['plot(W_2_ch_',num2str(p),', sort, green);']);
    eval(['plot(W_3_ch_',num2str(p),', sort, red);']);
    eval(['plot(W_4_ch_',num2str(p),', sort, cyan);']);
    eval(['plot(W_5_ch_',num2str(p),', sort, magenta);']);
    eval(['plot(W_6_ch_',num2str(p),', sort, yellow);']);
    eval(['plot(W_7_ch_',num2str(p),', sort, black);']);
    eval(['plot(W_8_ch_',num2str(p),', sort, blue);']);
    eval(['plot(W_9_ch_',num2str(p),', sort, green);']);
    eval(['plot(W_10_ch_',num2str(p),', sort, xred);']);
    eval(['plot(W_11_ch_',num2str(p),', sort, xcyan);']);
    eval(['plot(W_12_ch_',num2str(p),', sort, xmagenta);']);
    eval(['plot(W_13_ch_',num2str(p),', sort, xyellow);']);
    eval(['plot(W_14_ch_',num2str(p),', sort, xblack);']);
    eval(['plot(W_15_ch_',num2str(p),', sort, xblue);']);
    eval(['plot(W_16_ch_',num2str(p),', sort, xgreen);']);
end

% Plot the variance of each channel and superimpose them into the same plot
% for comparing the change in amplitude vs time.
figure(21)
hold on; box on;
set(gca, 'XLim', [1 16]);
plot(W_all_ch_1, blue); xlabel('Time(Minutes)'); ylabel('Variance'); title('Variance of subject (LBP Subject)'); grid on
plot(W_all_ch_2, green);
plot(W_all_ch_3, red);
plot(W_all_ch_4, cyan);
% This function allow us to identify the corresponding line of each channel.
legend('Channel 1', 'Channel 2', 'Channel 3', 'Channel 4');
Appendix D: Heel Strike Sensor Design and Schematic
**Calculation of R1**

Some initial conduction of the circuits: $V_{in} = 1.2V$ (Battery), $V_{out} = .005V$ (The max input voltage given that the gain of Delsys amplifier is 1000), $R_2$ (Foot sensor) = 500$\Omega$ (when heel strike occur)

\[
V_{out} = V_{in} \left( \frac{R_1}{R_2 + R_1} \right)
\]

$R_1 = 2.1\Omega$

\[
V_{out} = \frac{V_{in}R_1}{R_2 + R_1}
\]

\[
V_{out}(R_2 + R_1) = V_{in}R_1
\]

\[
V_{out}R_2 + V_{out}R_1 = V_{in}R_1
\]

\[
V_{out}R_2 + V_{in}R_1 - V_{out}R_1
\]

\[
V_{out}R_2 = R_1(V_{in} - V_{out})
\]

\[
R_1 = \frac{V_{out}R_2}{V_{in} - V_{out}}
\]

**Extra photo of the heel strike sensor**

The copper plate                      With the Conductive frame

The finishing of the Heel strike sensor
The circuit of connecting the heel sensor to the Delsys EMG recorder
Appendix E: Questionnaire
(Chinese Version)
Validation of the Chinese version of the Oswestry Disability Index

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Abstract. This study aimed to collect evidence on the structural and substantive validity, and test-retest reliability of the Chinese version of the Oswestry Disability Index (CODI). Seventy-nine patients suffering from chronic low back pain were assessed with the CODI. The results of explorative factor analysis primarily suggested a single-factor structure with nine out of 10 items (factor loading = 0.66–0.79). The sex life item was found to load on a different factor. The Cronbach’s alpha of all 10 items was 0.81 (\(p<0.05\)). When the sex life item was removed from the analysis, the alpha value was increased to 0.89 (\(p<0.05\)). The test-retest reliability was estimated based on 56 participants who completed two administrations of CODI in 48 hours. The intraclass correlation coefficient (ICC) computed for the total CODI scores was 0.86 (95% C.I. = 0.81–0.91). The reliability estimated for the item scores using Kappa statistics ranged from a high of \(k=0.80\) for the sitting item to a low of \(k=0.49\) for the traveling item. Kappa statistics were not available for three items. The Chinese version of the Oswestry Disability Index demonstrated satisfactory validity and test-retest reliability, and so could be considered as an appropriate instrument for assessing chronic back pain-related disability in Chinese patients in Hong Kong. Further research should address the cross-cultural and measurement issues in regard to sex life in order to further improve the test content of the instrument.

Keywords: Back pain, validity, Oswestry Disability Index

1. Introduction

Chronic low back pain is a common musculoskeletal disorder associated with disability in industrialized countries [9]. In the United States, the direct and indirect costs incurred from treating this condition are estimated to be at least $50 billion per year [2]. In Hong Kong, the prevalence of back pain in 1995 which resulted in noticeable disability was reported to be 69% [13]. The burden that people suffering from back pain put on the medical care system has become heavier and heavier. To further improve the effectiveness of interventions provided to clients suffering from chronic low back pain, rehabilitation therapists have sought for an accurate and valid instrument to measure their functional level after the back injury. Back-related function has also been regarded as a core treatment outcome for low back pain services and research [4].

The Oswestry Disability Index (ODI) or the Oswestry Low Back Pain Disability Questionnaire (ODQ) is a brief, self-administered questionnaire [6]. It is one of the most widely used outcome measures for clients with low back pain [1,4]. Other instruments include the visual analogue scale, the numeric pain rating scale, and pain drawing. However, among all of these instruments, ODI is the only one which adopts a condition-specific content and quantifies the disabling effects on daily living functioning due to the low back pain. The ODI consists of 10 items which cover different aspects of functioning: pain intensity, self care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. Each item is scored between 0 and 5, with higher values representing a greater extent of disabil-

\(\ast\)Corresponding author.
ity. According to previous studies, the ODI is simple to score and does not have any obvious flooring or ceiling effects [3]. The ODI has been demonstrated to have good content validity in terms of its consistency with the ICICH-2 categories [3,20]. Evaluation of its utilization has also indicated that the instrument is specific enough to be a measure of disability as defined by the World Health Organization [8]. The most updated version of the ODI is version 2.0, which resulted from the most recent revisions made by the Medical Research Council in the United Kingdom. Previous studies have reported evidence of the reliability and validity of this new version [7,8,11,17].

There are four versions of the ODI available in English and in nine other languages: Danish, Dutch, Finnish, French, German, Greek, Norwegian, Spanish, and Swedish [7]. The ODI has been widely adopted in local clinical work rehabilitation settings. However, a Chinese version has not been developed. In view of the clinical utility and usefulness of the instrument, there is a need to validate a Chinese version for use among Chinese people suffering from low back pain. This study aimed to collect evidence of the structural and substantive validity, and test-retest reliability of the Chinese-translated ODI Version 2.0. The relevance of its use to low back pain sufferers among the Chinese population of Hong Kong was also investigated.

2. Method

2.1. Participants

A total of 79 patients suffering from chronic low back pain were recruited to participate in this study. They were recruited by means of convenient sampling from the occupational therapy departments of four general hospitals in Hong Kong. The selection criteria were: 1) confirmed diagnosis of low back pain by an orthopedic surgeon; 2) currently experiencing low back pain symptoms, with or without neurological signs; 3) aged 60 years or below; 4) currently attending a return to work program at the participating occupational therapy department; and 5) had given their voluntary consent to participate in the study. The exclusion criteria were: having a previous history of back surgery, the back pain being a result of a medical disease, having an unstable back condition such as a fracture or a severe prolapsed vertebral disc and nerve root irritation, having cognitive impairment and/or psychiatric symptoms, and being pregnant.

Fifty men and 25 women took part in the study, and their mean age was 42.0 years ($SD = 9.7$). They were native Chinese speakers, they had good vision, they were able to read, and they suffered from low back pain with a stable condition. The mean duration of back pain was 13.5 months ($SD = 10.2$). The most common cause of back pain was a sprained back (66%). Other causes were back contusion, mild grade prolapsed intervertebral disk (13%), and mild grade spondylolisthesis (5%). The vast majority of the participants received their injury during their work (94%). Most of them (72%) had reached an education level equal to or above junior secondary school level. A majority of the participants were also construction site workers (28%). Other occupations held by them included airport porter, janitor, personal care worker, delivery worker, shop assistant, driver, cook, electrician, and mechanic. A small proportion of the participants (6%) were clerks and teachers.

2.2. The Chinese Oswestry Disability Index (CODI)

The original ODI was translated into a Chinese version in a pilot study conducted prior to this study. The translation was performed by a quality translator. The equivalence of the original and translated Chinese versions was evaluated by a review panel. The panel was composed of six occupational therapists with an average of 10.8 years of experience working with patients suffering from low back pain. The aspect on which the translated version was evaluated was the appropriateness and fluency of the translation. The review panel was also asked to evaluate the relevance and representativeness of the translated test content for assessing back-related disability among a Chinese population. A standardized questionnaire was used to guide the review. Discussion sessions were held to solicit the opinions of the panel members on necessary changes to the translated ODI.

The results obtained from the pilot study indicated that the sentence structure of four items (personal care, walking, sitting, and traveling) required further amendments; in particular, the Chinese wording needed to be changed. The content-related evidence revealed that the distance-based unit specified in the walking item was less relevant to the local environment than to a western environment. Instead, a time-based unit was deemed as more relevant. A sample of the CODI is presented in Appendix I of this paper. The trial test of the CODI was also conducted on 10 patients suffering from known low back pain. They were asked...
to complete the CODI and a semi-structured interview was conducted to solicit feedback from them on their level of understanding and the clarity of the questionnaire. The results indicated that all of them showed good understanding of the items and hence no further modification to the CODI was required.

2.3. Procedures

A total of four occupational therapists who specialized in work rehabilitation were responsible for screening the participants and administering the CODI to them. Their average length of experience was 9.6 years. All of them participated in the pilot study and had prior experience of using the CODI in their daily clinical practice. In addition, a training session was held to standardize the administrative procedure and rating criteria prior to the actual data collection. The purposes of the study were explained to the participants who satisfied the screening criteria and provided voluntary consent to join the study. Ethics approval was obtained from the ethics committee of The Hong Kong Polytechnic University.

The CODI was administered to the participants by one of the four occupational therapists. Within the week of test administration, the participants were not involved in physical capacity evaluation or modification of the work hardening program which they had been attending prior to the data collection. In the first testing, the participants were required to complete the CODI and a pain Visual Analogue Scale (VAS). The purpose of administrating the pain VAS was to monitor the pain level of patients at the time they completed the CODI. The second testing was conducted two days after the first one. Similarly, the participants completed the CODI and the pain VAS.

2.4. Data analysis

Explorative factor analysis using the principal component extraction method followed by varimax rotation was used to explore the factor structure of the CODI items as evidence of construct validity (SPSS 11.0 version). The intraclass correlation coefficient (ICC) and the Kappa coefficient were used to estimate the test-retest reliability of the total score and individual item scores on the CODI respectively. The internal consistency of the instrument was computed with Cronbach’s alpha and Pearson’s product-moment correlation coefficient.

### Table 1

<table>
<thead>
<tr>
<th>Items</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 Pain Intensity</td>
<td>2.24</td>
<td>0.90</td>
</tr>
<tr>
<td>Q2 Personal Care</td>
<td>1.72</td>
<td>1.09</td>
</tr>
<tr>
<td>Q3 Lifting</td>
<td>2.79</td>
<td>0.97</td>
</tr>
<tr>
<td>Q4 Walking</td>
<td>1.70</td>
<td>1.05</td>
</tr>
<tr>
<td>Q5 Sitting</td>
<td>2.49</td>
<td>1.00</td>
</tr>
<tr>
<td>Q6 Standing</td>
<td>2.46</td>
<td>1.02</td>
</tr>
<tr>
<td>Q7 Sleeping</td>
<td>1.96</td>
<td>1.26</td>
</tr>
<tr>
<td>Q8 Sex Life</td>
<td>2.91</td>
<td>1.55</td>
</tr>
<tr>
<td>Q9 Social Life</td>
<td>2.68</td>
<td>1.24</td>
</tr>
<tr>
<td>Q10 Traveling</td>
<td>2.24</td>
<td>1.27</td>
</tr>
</tbody>
</table>

**Total Index Score**: 45.66 (Range: 4.00–86.00)

### Table 2

<table>
<thead>
<tr>
<th>Latent Factors*</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 Pain Intensity</td>
<td>0.71</td>
<td>0.13</td>
</tr>
<tr>
<td>Q2 Personal Care</td>
<td>0.72</td>
<td>0.06</td>
</tr>
<tr>
<td>Q3 Lifting</td>
<td>0.66</td>
<td>0.38</td>
</tr>
<tr>
<td>Q4 Walking</td>
<td>0.79</td>
<td>−0.29</td>
</tr>
<tr>
<td>Q5 Sitting</td>
<td>0.79</td>
<td>−0.39</td>
</tr>
<tr>
<td>Q6 Standing</td>
<td>0.77</td>
<td>−0.24</td>
</tr>
<tr>
<td>Q7 Sleeping</td>
<td>0.71</td>
<td>0.27</td>
</tr>
<tr>
<td>Q9 Social Life</td>
<td>0.70</td>
<td>0.02</td>
</tr>
<tr>
<td>Q10 Traveling</td>
<td>0.76</td>
<td>−0.05</td>
</tr>
<tr>
<td>Q8 Sex Life</td>
<td>0.22</td>
<td>0.78</td>
</tr>
</tbody>
</table>

*Extraction method: principal component analysis; after varimax rotation.

3. Results

The mean CODI index score of the participants was 45.7 ($SD = 16.4$) and the range was between 4.0 and 86 (Table 1). The mean item scores ranged from a high of 2.9 ($SD = 1.5$) on the sex life item to a low of 1.7 ($SD = 1.0$) on the personal care item. Explorative factor analysis was conducted on the 10 items. The KMO measure was 0.89 and Bartlett’s Test of Sphericity was significant. A two-factor structure was obtained which accounted for 60.7% of the total variance (Table 2). The first factor consisted of nine items with all factor loadings above 0.65. The highest factor loading was from the sitting item (0.79), whilst the lowest was from the lifting item (0.66). The second factor had one item – the sex life item – which accounted for 11.3% of the total variance. The factor loading of this item was 0.79.

The results of item analysis indicated that the item-total correlations (discriminative indices) ranged from a high of $r = 0.64$ for the walking item to a low of $r = 0.19$ for the sex life item (Table 3). The majority
Table 3

<table>
<thead>
<tr>
<th>Items</th>
<th>Corrected Item-Total Correlation R</th>
<th>Squared Multiple Correlation R²</th>
<th>Alpha iif Item Deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 Pain Intensity</td>
<td>0.58</td>
<td>0.47</td>
<td>0.79</td>
</tr>
<tr>
<td>Q2 Personal Care</td>
<td>0.61</td>
<td>0.43</td>
<td>0.78</td>
</tr>
<tr>
<td>Q3 Lifting</td>
<td>0.58</td>
<td>0.41</td>
<td>0.79</td>
</tr>
<tr>
<td>Q4 Walking</td>
<td>0.64</td>
<td>0.60</td>
<td>0.78</td>
</tr>
<tr>
<td>Q5 Sitting</td>
<td>0.63</td>
<td>0.68</td>
<td>0.78</td>
</tr>
<tr>
<td>Q6 Standing</td>
<td>0.63</td>
<td>0.60</td>
<td>0.78</td>
</tr>
<tr>
<td>Q7 Sleeping</td>
<td>0.63</td>
<td>0.45</td>
<td>0.78</td>
</tr>
<tr>
<td>Q8 Sex Life</td>
<td>0.19</td>
<td>0.12</td>
<td>0.89</td>
</tr>
<tr>
<td>Q9 Social Life</td>
<td>0.59</td>
<td>0.45</td>
<td>0.78</td>
</tr>
<tr>
<td>Q10 Traveling</td>
<td>0.64</td>
<td>0.51</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Cronbach’s alpha = 0.81.

Table 4

<table>
<thead>
<tr>
<th>Items</th>
<th>Kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 Pain Intensity</td>
<td>0.57</td>
</tr>
<tr>
<td>Q2 Personal Care</td>
<td>0.52</td>
</tr>
<tr>
<td>Q3 Lifting</td>
<td>—</td>
</tr>
<tr>
<td>Q4 Walking</td>
<td>0.64</td>
</tr>
<tr>
<td>Q5 Sitting</td>
<td>0.80</td>
</tr>
<tr>
<td>Q6 Standing</td>
<td>—</td>
</tr>
<tr>
<td>Q7 Sleeping</td>
<td>0.65</td>
</tr>
<tr>
<td>Q8 Sex Life</td>
<td>—</td>
</tr>
<tr>
<td>Q9 Social Life</td>
<td>0.74</td>
</tr>
<tr>
<td>Q10 Traveling</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Due to asymmetric distributions of the ratings between the two testing occasions.

4. Discussion

The results of this study indicate that the Chinese version of the Oswestry Disability Index possessed satisfactory psychometric properties in terms of its structural and substantive validity, and test-retest reliability. There was one item – sex life – which was deemed problematic according to the findings from the factor and item analysis. The problems revealed could have originated from the cultural sensitivity over issues related to sex or from sampling biases.

The two-factor structure revealed in the results of explorative factor analysis suggests that the sex life item relates poorly to the other nine items. The contents of these nine items largely concern how pain affects the performance on daily activities of personal care, standing, walking, and lifting. Our findings are inconsistent with those reported from other studies on the original ODI. According to these studies, pain appeared to positively correlate with the disability on sexual activity [14,15,18]. In other words, it would be expected that the sex life item would form a single factor with the other CODI items. In this study, the sex life item was found to load on a different factor (a one-item factor). An inspection of the item statistics reveals that the sex life item had the highest item difficulty level (i.e. mean = 2.91) and the highest variation among the participants (i.e. SD = 1.55). What this means is that the disability as perceived by the participants was high when they engaged in sexual activities. However, this perception was also the least consistent among the participants when compared with other aspects of daily living tasks. There are a few reasons that account for this
The perception of sex life is a complicated matter which involves both physical and psycho-emotional perspectives [14]. Maigne and Chatellier further elaborated on the elements which are thought to relate both to low back pain and one’s sex life. They are the physical pain induced by coital positioning and pelvic movement, the fear of disappointing one’s partner, the depressive mood associated with the disability, and the lack of interest in sexual activity. The rating on the sex life item would be susceptible to the influence of Chinese cultural beliefs; particularly psycho-emotional factors. More importantly, sex life is also a function of the presence and desirability of a partner. All these factors might lead to either under- or over-reporting of problem. In the present study, it seems the participants over-reported the problems they encountered in their sex life. The level of inconsistency among the participants was also high. Nevertheless, the scope of this study did not allow us to further explore the mechanism behind this observation.

The internal consistency of the CODI was found to be satisfactory (0.70–0.90 criteria) [5] with its value being comparable to those in studies conducted on the original version (\( \alpha = 0.81 \)). Our study reported indices ranging from 0.71 to 0.87 [8,11,17,19]. As expected, the sex life item had a low item-total correlation coefficient (\( r = 0.19 \)). The removal of this item increased the internal consistency to \( \alpha = 0.89 \). The test-retest reliability of the CODI total score was regarded as good [16] (ICC = 0.86; 95% C.I. = 0.81–0.91). Our findings are comparable to the test-retest study conducted by Gronblad, in which the index obtained for the original ODI was 0.83 (ICC, one week apart) [10]. The value obtained from Davidson and Keating’s study was 0.84 (ICC, 6 weeks apart) [3]. Two other studies reported higher test-retest reliability: the original study by Fairbank, in which the value was 0.99 (Pearson’s r, less than 24 hours) [6], and the study by Kopec, which reported a value of 0.93 (ICC, 4 days) [11]. The discrepancies among the reliability indices could be due to the differences in the period of time between the test (first assessment) and retest (second assessment). The longer the period is, the more the results are confounded by other factors such as natural recovery or the intervention effect.

The test-retest reliability of the item scores of the CODI was regarded as satisfactory with Kappa values being moderate and good (\( K = 0.49 \) to 0.80) [12]. However, due to the comparatively small sample size, there were three items, including the sex life item, for which Kappa could not be computed.

In general, the CODI is a short disability measure specifically designed for patients suffering from low back pain. Comments from the participants indicated that the content of the CODI was acceptable to them. They also reflected that the items were easy to comprehend. In this study, most of the participants completed the instrument in five minutes or less. The results of this study revealed satisfactory structural and substantive validity, and test-retest reliability. However, the sex life item did not seem to fit well with the rest of the items, and hence it has less than satisfactory item-total relationship and consistency. In view of this, further studies should explore the reasons behind the lack of fit of the sex life item. Nevertheless, the CODI is worth being used as a standardized assessment of the disabilities of patients associated with low back pain. The findings of this study are limited by the characteristics of the participants, who suffered from low back pain with a stable back condition. At the time of the data collection, they were receiving active work rehabilitation. The results therefore are not readily applicable to those who are in the acute phase of back pain or have an unstable back. The comparatively small sample size for the factor and item analysis could also limit the validity of the results. Future studies should replicate the validation procedure for other groups of low back pain patients. A large sample size would yield more stable results; particularly regarding the test-retest reliability of the items.

5. Conclusion

This study has validated the Chinese version of the Oswestry Disability Index (ODI). Our findings have provided more evidence of the psychometric properties of the instrument, which support its use with Chinese patients who suffer from low back pain but with a stable back. Future research should focus on gathering more evidence on applications of the instrument to different types of low back pain patients. Cultural issues relating to low back pain and engagement in sexual activities of patients are worthy of further investigation.

Acknowledgements

The authors would like to thank Winkie Chan, Jodi Ip, Carman Li, and Margaret Pang (from Tuen Mun Hospital), Iris Chan (from Pamela Youde Nethersole Eastern Hospital), Rosalia Lee (from Queen Elizabeth Hospital), and Ken Chung (from United Christian Hospital) for their help with data collection and the implementation of this project.
References


腰背痛问卷调查

请填写这份问卷，帮助我们了解你的背痛（或脚痛）如何影响您的日常生活。请回答所有问题，每题请只选择一个最能描述您今天背痛／脚痛情况的答案。

1. 痛楚程度
   □ 现在没有任何痛楚。
   □ 现在只感到轻微的痛楚。
   □ 现在感到中等程度痛楚。
   □ 现在感到非常痛楚。
   □ 现在的痛楚程度非常严重。
   □ 现在感到极度痛楚，痛楚的程度非其他能够想像。

2. 个人起居（梳洗、穿衣等）
   □ 我可以如常的照顾自己，不会感到任何额外的痛楚。
   □ 我可以如常的照顾自己，但感到非常痛楚。
   □ 照顾自己时感到痛楚，需小心及缓慢行动。
   □ 我能应付大部分的起居生活，但需要其他人的一些帮助。
   □ 我每天都需要别人帮助照顾大部分的起居生活。
   □ 我不能够自己穿衣，梳洗也有困难，只可以卧床休息。

3. 提起物件
   □ 我可以提起很重的物件，而不会造成额外的痛楚。
   □ 我可以提起很重的物件，但会造出额外的痛楚。
   □ 疼痛使我不能从地上提起很重的物件，但假如物件放在一个适当的位置，我仍可以拿起。
   □ 疼痛使我不能提起很重的物件，但假如物件放在一个适当的位置，我可以拿起一些轻便或不太重的物件。
   □ 我只可以提起一些非常轻的物件。
   □ 我根本不能提起任何物件。

4. 步行
   □ 疼痛不会影响我步行多少路程。
   □ 疼痛使我不能步行多过一小时。
   □ 疼痛使我不能步行多过半小时。
   □ 疼痛使我不能步行多过十五分钟。
   □ 我需要用拐杖行路。
   □ 我大部分时间卧床，只能爬去洗手间。
5. 坐下
- 我可坐在任何座椅上多久也沒有問題。
- 我可坐在家常的座椅上多久也沒有問題。
- 疼痛使我坐不過一小時。
- 疼痛使我坐不過半小時。
- 疼痛使我坐超過十五分鐘。
- 疼痛使我根本不能坐。

6. 站立
- 我可以站很久也不會造成額外的痛苦。
- 我可以站很久，但會有額外的痛苦。
- 疼痛使我不能站立超過一小時。
- 疼痛使我不能站立超過三十分鐘。
- 疼痛使我不能站立超過十分鐘。
- 疼痛使我完全不能站立。

7. 眠眠
- 疼痛從不影響我的睡眠。
- 有時候疼痛影響我的睡眠。
- 疼痛使我無法睡眠超過六小時。
- 疼痛使我無法睡眠超過四小時。
- 疼痛使我無法睡眠超過二小時。
- 疼痛使我根本不能入睡。

8. 性生活（註：如沒有性生活，毋須填寫此欄）
- 我的性生活正常，沒有任何額外的痛楚。
- 我的性生活正常，但有額外的痛楚。
- 我的性生活正常，但非常疼痛。
- 痛楚嚴重限制了我的性生活。
- 痛楚影響了性關係，我差不多沒有性生活。
- 疼痛使我根本不能有性生活。

9. 社交生活
- 我的社交生活正常，沒有引起任何額外的痛楚。
- 我的社交生活正常，但會增加痛楚的程度。
- 疼痛不太影響我的社交生活，但使我不作一些較為劇烈的活動，例如運動等。
- 疼痛限制了我的社交生活，使我不能參加社交活動。
- 疼痛限制了我的社交生活，我只能在家活動。
- 疼痛的關係，我根本沒有任何社交生活。

10. 舟車勞頓
- 我可以去任何地方，而旅途上的勞頓不會引起任何痛楚。
- 我可以去任何地方，但旅途上的勞頓造成額外的痛楚。
- 虽然很痛，但我仍可作多於兩小時的旅程。
- 疼痛使我只可以作一小时的旅程。
- 疼痛使我只可以作少於三十分鐘的短途旅程。
- 除了外出接受治療，疼痛使我根本不能有任何舟車勞頓。
Appendix F: Questionnaire
(English Version)
Questionnaire

Date: __/__/__

1. ID: ___________________

2. Gender: Male  Female

3. Age: ________________

4. Height: _________cm    Weight: _________kg

5. Do you have pain in your lower lumbar now?
   Yes  No
   If Yes identify the type of pain it cause from: Muscle/Articular/ other________
   Identify the location of the pain occur: L1 / L2 / L3 / L4 / L5 / other________.

6. Have you ever had pain in your lower lumbar?
   Yes  No
   If Yes when it happened:__________________.

7. Have you ever injured your lower lumbar?
   Yes  No
   If Yes when it happened:__________________.

8. Have you ever had surgery involving your spine or other back muscles?
   Yes  No
   If Yes when it happened:__________________.
9. Please tick a box ∀ on the check list for neuromuscular disorders
   
   Yes : You have currently this problem.
   
   Ever : You have ever had this problem.
   
   Never : You have never had this problem.
   
   Unknown : You do not know whether you have had ever this problem or not.

<table>
<thead>
<tr>
<th>Check list for neuromuscular disorders</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Meningitis</td>
</tr>
<tr>
<td>b) Trauma</td>
</tr>
<tr>
<td>c) Seizure disorders</td>
</tr>
<tr>
<td>d) Sleep disorders</td>
</tr>
<tr>
<td>e) Stroke</td>
</tr>
<tr>
<td>f) Brain tumour</td>
</tr>
<tr>
<td>g) Fibromyalgia</td>
</tr>
<tr>
<td>h) Neurological deficit</td>
</tr>
</tbody>
</table>

10. Do you have any other known condition affecting your musculoskeletal or nervous system not in a list of question 10 a) to h) above?
   
   Yes □ No □

12. Is there any difference in the length of your legs due to any condition you might ever had eg. injury etc.
   
   Yes □ No □

Please describe below if you answered YES to any of the questions above:

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Appendix G Ethics Approval Letter
(From The University of Hong Kong)
Dr. Yong Hu  
Dept. of Orthopaedics and Traumatology  
Duchess of Kent Children’s Hospital  
17-May-07  
Dear Dr. Hu,

IRB Reference Number: UW 07-196

The HKU/HA HKW IRB is authorized by a joint agreement of the University of Hong Kong and Hospital Authority Hong Kong West Cluster to review and monitor clinical research. It serves to ensure that research complies with the Declaration of Helsinki and acts in accordance to ICH GCP guidelines, local regulations and Hospital Authority and the University policies.

I write to inform that your research application/submission has been approved by an expedited process with details shown below. You are also requested to adhere to the conditions listed.

Date of expedited review: 16-05-2007 (Date/Month/Year)

IRB reviewer(s): Professor Cl Lai, Chairman and Dr. MF Yuen, Deputy Chairman of the HKU/HA HKW IRB

Protocol title: Surface EMG and stiffness detection to quantify the lumbar mechanics of low back pain patients

Study site(s): Queen Mary Hospital and Duchess of Kent Children's Hospital

Document(s) approved: 01. Clinical research ethics review application form  
2. Protocol  
3. Information sheet and written consent form - English and Chinese  
4. Oswestry disability questionnaire - English and Chinese

Document(s) reviewed: 05. Short CV of principal investigator

(Conditions:  
1. Do not deviate from, or make changes to the study protocol without prior written IRB approval, except when it is necessary to eliminate immediate hazards to research subjects or when the change involves only logistical or administrative issues.  
2. Report the following to HKU/HA HKW IRB: (i) study protocol or consent document change (use 'HKU/HA HKW IRB RE001F7'), (ii) serious adverse event (use 'HKU/HA HKW IRB RE001F8'), (iii) study progress (use 'HKU/HA HKW IRB RE001F9a') * (iv) new information that may be relevant to a subject's willingness to continue participation in the study.  
3. Report study progress to HKU/HA HKW IRB at a 12-monthly interval until study closure.)

Yours sincerely,

W. H. Lee  
Secretary, HKU/HA HKW IRB