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# Biodynamic Parameters During a Step Down Task in Subjects with Chronic or Recurrent Low Back Pain Classified with Lumbar Instability

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Biodynamic parameters during a step down task in subjects with chronic or recurrent low back pain classified with lumbar instability

By

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 Date April 28, 2015

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## ABSTRACT

Biodynamic parameters during a step down task in subjects with chronic or recurrent low back pain classified with lumbar instability

By

Kim M. Poulsen

**Background:** Low back pain (LBP) affect a majority of the population. Lumbar instability has been identified as a factor in a significant portion of individuals with LBP but movement characteristics of this population has seen limited research regarding functional tasks. **Objective:** This study examined biodynamic parameters during a step task. **Design:** Quasi-experimental with 2 factors, group and side (L/R), and 1 repeated measure (stepping). **Statistics:** Two-way Mixed-Design Repeated Measures ANOVA with Alpha = .05. **Movement task:** Subjects with LBP and lumbar spine clinical instability classification (N=11) and control subjects (N=11) performed a step down task from a 9.5 inch height on left and right side. **Main outcomes:** sEMG activation (%MVC), sEMG onset time at first weight acceptance, Ground Reaction Force; rise time GRF(z) and 3D trunk range of motion (ROM) related to three phases of the step: (1) First single leg support, (2) double support and (3) second single leg support. **Main results:** ROM was reduced in the LBP group in the full step

phase in the sagittal plane ( $p=.003$ , power= .99), in the final phase in the frontal plane ( $p=.021$ , power=.99) and in the transverse plane ( $p=.018$ , power=.99) on left steps. **GRF(z)** was slower in the LBP group at first weight acceptance when leading with the left leg ( $p=.016$ , power= .99). **EMG onsets:** The LBP group had delayed muscle onsets of the right hip abductors ( $p=.043$ , power=.99), left abdominals with left stepping ( $p=.008$ , power=.91) and right lumbar extensors with right stepping ( $p=.025$ , power=.93). The LBP group had delayed onset of right lumbar extensors with right stepping but earlier onset with left stepping ( $p=.025$ , power.93). **EMG activation levels** was higher in the LBP group in both left and right steps of right lumbar extensors ( $p=.047$ , power=.93), right hip abductors ( $p=.017$ , power= .68) and left hip abductors ( $p= .035$ , power= .96). **Conclusion:** Subjects with LBP demonstrated a high-load movement strategy during this low-load step task with reduced ROM, increased muscle activation, delayed muscle onsets and slow GRF(z) rise time. Left stepping presented more challenge for this group of predominantly right-footed subjects with LBP classified with lumbar instability.

## I. INTRODUCTION

### Background

When an individual suffers from low back pain (LBP) it can have a significant effect on his or her ability to perform daily tasks (ADLs) including walking and negotiating stairs. Facing difficulties with ADLs including walking, an indicator of independent living, can precipitate a disability leave from work (Atlas and Deyo, 2001, Pengel et al., 2003), reduced quality of life (Haag et al. 2007) and foster a fear of movement and activity in anticipation of pain (Buer et al., 2002, Denison et al., 2004, Waddell, 1993).

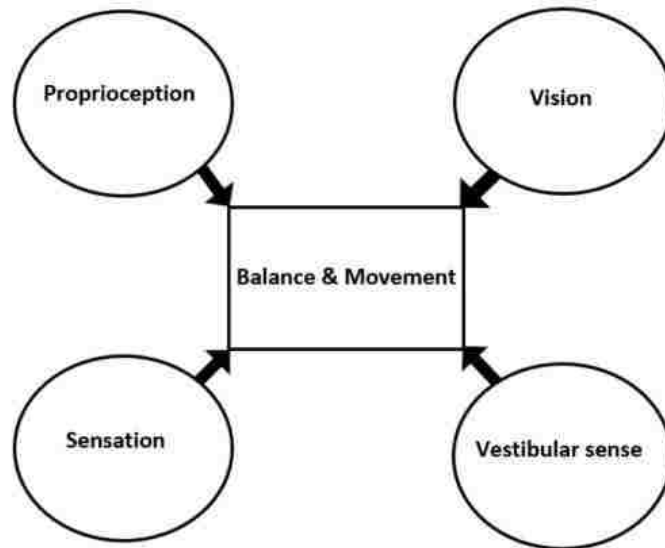
The acute onset of LBP is often self-limiting and pain resolves within a few weeks and the individual resumes normal activities. However, in many cases the LBP is recurrent (Hides & Richardson, 1996) or becomes chronic and the individual may experience limitations in functional capabilities (Barstow et al., 1998). Treatment options for LBP are vast and varied in effectiveness (Barstow et al., 1998; Parker et al, 2014) and have in the past been prescribed broadly without much considerations to individual characteristics regarding symptomology, origin of pain, history etc. but developments in rehabilitation coupled with evidence based practice (Philadelphia Panel, 2001) has promoted a trend toward classification of individuals with LBP into treatment protocols with

much better outcomes regarding pain and function (Dagenais et al., 2010). Some examples of classification are “derangement syndrome” suggesting a McKenzie approach (Petersen et al., 2007), “acute LBP” suggesting spinal manipulation (Flynn et al., 2002; Fritz et al., 2004) and “lumbar stenosis” suggesting manual therapy and a flexion exercise approach (Whitman et al., 2006). Recently it has been recognized that in many individuals with LBP there is a component of functional instability of the lumbar spine (Cook et al., 2006) with abnormal trunk muscle function and change in movement patterns during gait, sit-to-stand and stair ascending (Lamoth et al., 2006; Lee et al., 2013; Selles et al., 2001). Some effective treatment strategies are starting to emerge focusing on spinal stabilization and muscle control (Hides et al., 2001; McGill, 2009; Moseley, 2002; O’Sullivan, 1997; O’Sullivan, 1998; Sung, 2003). An emerging body of research have been studying step negotiation in individuals with LBP, however no studies have comprehensively examined trunk movement patterns, and postural control and muscle function in a stair negotiation task in individuals classified as having spinal instability. Such a study could further illuminate the changes in motor control, posture and muscle function in a population with chronic or recurrent LBP. The present study is such an endeavor.

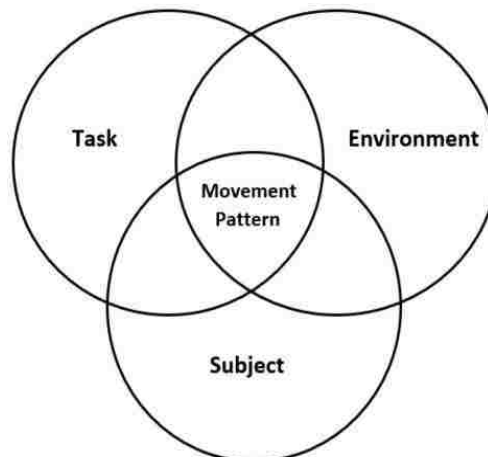
## Theoretical framework

The dynamics systems model (Shumway-Cook & Woollacott, 1995) serve as the theoretic framework for this project. The model describes how the human body in motion engage in a dynamic interaction with between the body, the environment and the given task. Furthermore it illustrate how the body adapts to changing demands of a movement task by utilizing proprioceptive, sensory and visual feedback (see figure 1) to adjust the specifics of a certain motion i.e. speed, direction, force etc. In context of a dynamic system model Gentile illustrate how the performer interact with the specific task regarding challenge level, environmental context (i.e. moving or stable surface) and whether the performer is manipulating an object as in grasping or holding an object (Gentile, 1998). The inputs and feedback from all these systems interact and ultimately aid in completion of the task (see figure 2). To exemplify this related to the current project; When an individual is about to step down from one level to a platform 9.5 inch lower, the individual has to determine, mostly via automatized motor planning, the safety of the task, distance involved, which limb to move, how much to elevate the leading leg, when to start lowering the leg over the edge, how much to hold back or brake with the trailing leg and how hard to impact on the lower surface to name a few of the factors involved.





*Figure 1.* Motor control and balance is accomplished utilizing feedback from all sensory systems. Diagram by Kim M. Poulsen.



*Figure 2.* Movement patterns is generated as a result of characteristics and constraints within the subject, the environment and the demands of the task. Diagram by Kim M. Poulsen.

### Research question

This project sets out to answer the question if there are differences between control subjects and individuals with LBP in biodynamic parameters, specifically muscle activation level, trunk movement and postural control via GRF during a functional step down task.

### Purpose of the study

The purpose of this study is to first, examine potential differences in trunk movement, postural muscle activation and ground reaction force between healthy controls and individuals with chronic or recurrent low back pain (LBP) classified with lumbar instability performing a step down task. Second, the purpose is to discuss any potential differences between the groups and thirdly, to propose clinical implications and direction for further research.

## Research Hypotheses

General questions:

I: Do subjects with chronic or recurrent LBP classified with lumbar instability present trunk movements, postural muscle activity and postural control different than control subjects during a step down task?

II: Does the methodology yield reliable muscle sEMG?

### Specific hypotheses:

H1: There will be a difference in ROM of the trunk in phases 2 & 4 between subjects with and without LBP with respect to side (L/R).

- H1a: There will be a difference in ROM of the trunk in phases 2 & 4 within subjects (with and without LBP) with respect to side (L/R).
- H1b: There will be a difference in ROM of the trunk in phases 2 & 4 between subjects (with and without LBP) with respect to side (L/R).
- H1c: There will be an interaction in ROM of the trunk in phases 2 & 4 between subjects (with and without LBP) and side (L/R).

H2: There will be a difference in ROM of the trunk in the full step, phases 2 through 4 between subjects with and without LBP with respect to side (L/R).

- H2a: There will be a difference in ROM of the trunk in the full step, phases 2 through 4 within subjects (with and without LBP) with respect to side (L/R).
- H2b: There will be a difference in ROM of the trunk in the full step, phases 2 through 4 between subjects (with and without LBP) with respect to side (L/R).
- H2c: There will be an interaction in ROM of the trunk in the full step, phases 2 through 4 between subjects (with and without LBP) with respect to side (L/R).

H3: There will be a difference in postural muscle activity in phases 2 & 4 between subjects with and without LBP with respect to side (L/R).

- H3a: There will be a difference in postural muscle activity in phases 2 & 4 within subjects (with and without LBP) with respect to side (L/R)
- H3b: There will be a difference in postural muscle activity in phases 2 & 4 between subjects (with and without LBP) with respect to side (L/R)
- H3c: There will be an interaction in postural muscle activity in phases 2 & 4 between subjects (with and without LBP) with respect to side (L/R).

- H4: There will be a difference in postural muscle activity in the full step, phases 2 through 4 between subjects with and without LBP with respect to side (L/R).
- H4a: There will be a difference in postural muscle activity in the full step, phases 2 through 4 within subjects (with and without LBP) with respect to side (L/R).
  - H4b: There will be a difference in postural muscle activity in the full step, phases 2 through 4 between subjects (with and without LBP) with respect to side (L/R).
  - H4c: There will be an interaction in postural muscle activity in the full step, phases 2 through 4 between subjects (with and without LBP) with respect to side (L/R).
- H5: There will be a difference in postural muscle onsets at first weight acceptance (P3) between subjects with and without LBP with respect to side (L/R).
- H5a: There will be a difference in postural muscle onsets at first weight acceptance (P3) within subjects (with and without LBP) with respect to side (L/R).
  - H5b: There will be a difference in postural muscle onsets at first weight acceptance (P3) between subjects (with and without LBP) with respect to side (L/R).

- H5c: There will be an interaction in postural muscle onsets at first weight acceptance (P3) between subjects (with and without LBP) with respect to side (L/R).

H6: There will be a difference in Ground Reaction Force between subjects with and without LBP at first weight acceptance (P3).

- H6a: There will be a difference in Ground Reaction Force within subjects (with and without LBP) at first weight acceptance (P3).
- H6b: There will be a difference in Ground Reaction Force between subjects (with and without LBP) at first weight acceptance (P3).
- H6c: There will be an interaction in Ground Reaction Force between subjects (with and without LBP) at first weight acceptance (P3).

H7: sEMG will be reliable

### Significance of the Study

As a significant number of individuals in the population of LBP sufferers have a component of spinal instability results from this study has the potential to inform researchers and rehabilitation specialist about muscle function, balance and motor control in this population assisting in furthering studies and guide rehabilitation strategies.

### Operational definitions

- Biodynamics:

Biodynamics is the human movement parameters expressed in integrated data from kinematics (relative segment angles), sEMG (surface muscle activity in mVolts) and kinetics (Center of Pressure).

- Center of Pressure (COP):

The COP is calculated from the ground reaction forces on the force platform and is the location on the platform where the resultant vertical force vector would act if it could be considered to have a single point of application.

- Low back pain:

Low back pain is defined as either chronic or recurrent low back pain:

Chronic LBP is defined as lasting 3 months or more and recurrent LBP as having more than one episode lasting 3 months or more the past one year. The pain will be objectified via the VAS pain scale and the modified Oswestry Pain and Disability Questionnaire.

- Lumbar instability

Lumbar instability is defined as the subjective report of one of the following symptoms: The back “giving way” or “giving out”, a need to pop or crack the back, painful locking of back, pain during transitions as sit-to-stand, increased pain returning upright from forward bending, pain with trivial movements, difficulty with unsupported sitting, worse with sustained positions, shorter intervals between bouts of pain, relief with back brace or corset or having frequent muscle spasms in addition to have 1 of 2 clinical instability tests positive (Prone instability test, Passive Lumbar Extension test).

- Step down

A step down is defined as the task of descending a 9.5 inch step on a platform in a movement science lab.

- Integrated sEMG

Integrated sEMG is the summarized sEMG signal in mVolts.

- Mean sEMG

The mean sEMG is defined as the mean sEMG in % of MVC.

- EMG onset

EMG onset is defined as 3 SD above baseline EMG signal

- Phase 1 (no data reported from this phase)

Phase 1 starts as data collection commences (double leg stance).



- Phase 2

Phase 2 is defined as the time from when the leading foot leaves the upper platform until it first touches the lower platform (single leg stance).

- Phase 3

Phase 3 is defined as the time from when the leading foot first touches the lower platform until the trailing foot leaves the upper platform (double leg stance)

- Phase 4

Phase 4 is defined as the time from when trailing foot leaves the upper platform until it first touches the lower platform (single leg stance).

- Postural muscles

Postural muscles are defined as the trunk flexor muscles (primarily rectus abdominus), low back extensors (primarily erector spinae), gluteus medius and calf muscles on left and right side.

(specifically gastrocnemius medial head).

## II. REVIEW OF RELATED LITERATURE

### Epidemiology of low back pain

Low back pain is one of the most prevalent medical conditions responsible for a large portion of medical visits. It is estimated that the prevalence of LBP is 6.8% of the North American population and that 80% will experience LBP during their lifetime (Bener, et al., 2014, Kent & Keating, 2005; Loney & Stratford 1999; Swinkels et al., 2014) and 75% will at some point in their life seek treatment for it (Barstow, Gilliam & Bishop, 1998). With physical therapists specializing in rehabilitation of movement-related disorders (APTA, 2014) it can easily be understood why individuals seeking treatment for LBP in many cases will receive physical therapy. Indeed, it is reported that about 50% of visits to outpatient physical therapy clinics are for pain and dysfunction related to LBP (Mielenz, 1997; Scheele et al., 2014).

### Etiology of low back pain

The origin of LBP cannot be discerned in many cases (Magee, 2002) and idiopathic LBP accounts for a majority of reported LBP (Atlas et al., 2001). Some physiological causative factors have been attributed to lumbar disc herniation, degenerative disc disease, osteoarthritis, anatomical abnormalities including scoliosis and other changes of bony structures and fibromyalgia. Individuals may also experience LBP related to injuries, trauma, obesity, poor posture, sedentary lifestyle and poor general health (Patel & Ogle, 2008). Other predisposing factors for experiencing LBP are anatomical abnormalities including scoliosis. Related joints such as the hip joints and the sacro-iliac joints (SI joints) have also been linked to LBP (Scwarzer et al., 1995). Some controversy exist about the SI joints ability to move and therefore the joint's ability to experience a dislocation or subluxation often ascribed as a causative factor for SI joint pain (Manchikanti et al., 2001). The hip joints may contribute to LBP through differences in available motion between left and right hip joint or limited mobility in hip flexion and extension (Ellison et al., 1990; Mellin, 1988).

Psychological factors have been linked to LBP as fear of movement is often present with acute LBP with the individual avoiding activities assumed to cause further pain. In most individuals, as pain subsides, there is a resumption of normal activities. However in some individuals the fear avoidance behavior

persists beyond the recovery of the actual injury. This may lead to maladaptive behaviors that negatively affect their function as the imposed reduction of activities may lead to loss of strength, endurance and mobility. This could be viewed as a vicious cycle that reinforces the impaired status of the individual (Fritz et al., 2001). The severity of this so-called fear-avoidance behavior corresponds with the length of recovery and length of disability from work (Fritz et al., 2001; Waddell, 1987; Wlaeyen & Crombez, 2007): Higher levels of fear avoidance displayed during the acute phase of LBP increase the likelihood is for a prolonged recovery and disability.

Weak trunk muscles, including the lumbar extensor muscles, predicted a higher risk for LBP in the year following onset of LBP (Luoto et al., 1995) thought to be due to the trunk muscles not being able to adequately support and protect the spine making it more vulnerable to injury.

Poor posture, often described as forward slumped upper back and reduced lumbar lordosis, has been ascribed having a negative effect on the lumbar spine (Scannell & McGill, 2003). Due to prolonged positioning beyond a neutral positioning, the tissue in the lumbar spine in particular the discs and ligaments experience deformation which in them-self can produce pain and if sustained also can lead to tissue degeneration (McKenzie, 2003).

Repetitive strain experienced by the industrial worker performing intense manual material handling has also been linked to an increased likelihood of

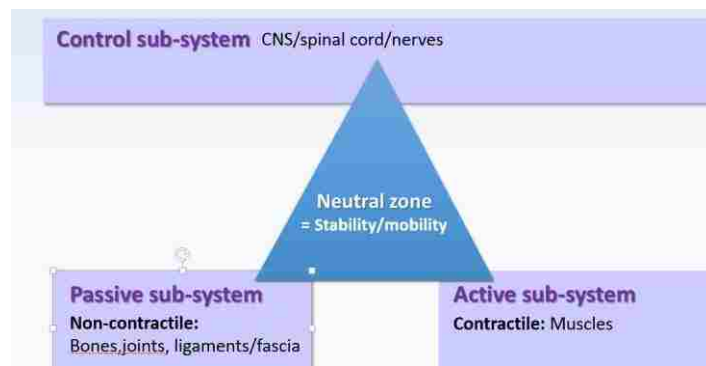
developing LBP (Marras et al., 1995 and 2001): Specifically higher lifting frequency, load moments, trunk velocity laterally and rotationally and trunk sagittal angle were found to be predisposing factors for LBP in industrial workers.

### Functional consequences of low back pain

One of the functions of the spine are to protect the spinal cord, assist the body in maintaining an upright position, keep the head upright allowing for gaze stabilization and stabilize the trunk and abdomen (McKenzie, 2003; Shumway-Cook & Woollacott, 1995). In order to serve these functions the spine must provide a stable base securing the spinal cord, yet at the same time allow motion to occur to accomplish everyday tasks such as bending to tie a shoe, rising from a chair and walking. The motion of the trunk is made possible by the segmental mobility between the joints of the spine. Whereas the lumbar spine has a great demand for mobility, a mechanism must exist to control this mobility in order not to strain or injure tissue.

Panjabi (1992) described what he termed a model of the spine-stabilizing system that has been widely accepted as an explanation of how the spine functions to insure stability (Richardson et al., 1999; McDonald et al., 2006;

McGill, 2003). The model describes the function of the spine as comprised of three subsystems: (a) The passive subsystem comprised of non-contractile tissue such as the vertebrae, ligaments and tendons, (b) the active subsystem comprised of muscles; and (c) the control subsystem comprised of the central nervous system (CNS), the spinal cord and associated nerves (see figure 3). The three sub-systems interact, as a dynamic system, in concert with each other to accomplish a balance between allowing the motion needed in the spine and the physiological limits of the spinal segments. An interruption or impairment in one of the subsystems can compromise the interaction and result in pain and dysfunction of common every- day functions including sit-to-stand, forward bending and walking.



*Figure 3.* Diagram of Panjabi's model of the spinal stabilizing system. Diagram by Kim M. Poulsen.

## Gait and LBP

Walking requires basic locomotor patterns that ensure a balance between motion of the body and the stability needed to effectively move forward in space without falling (Shumway-Cook & Woollacott, 1995). Human locomotion demonstrate a reciprocal pattern between the extremities and the trunk. This is seen when one leg swings forward to reach the ground; the contra-lateral arm swings in sync with the lower extremity (LE) while the ipsilateral arm swings opposite. The ipsilateral pelvis rotates forward a few degrees with the swing-leg at time of heel contact, and has a slight anterior tilt associated with a slight trunk forward lean (Nordin & Frankel, 2001). This forward lean is likely necessitated by the need for the center of mass (COM) to move forward as the body moves forward. At the point of heel contact, the pelvis is also tilted upward on the contra-lateral side to allow for floor clearance of the swing leg and assist in moving the trunk slightly over the stance leg (Hamil & Knutzen, 2001; Nordin & Frankel, 2003). At slow walking speed, the pelvis and trunk approximates being in phase with the trunk matching the minor rotation of the pelvis (Lamoth et al., 2004). At normal gait speed the rotation of the pelvis is about four degrees coupled with a lateral shift of pelvis reducing the need to translate the body's' center of mass as the forward placement of the pelvis places the hip closer to the stance leg (Inman et al., 1981). At faster gait speeds the velocity increase

of the rotational movement in the horizontal plane of the pelvis is attenuated by a trunk counter rotation (Lamoth et al., 2004). The arm-swing associated with the trunk rotation, but opposite the ipsilateral leg, is thought to regulate the body rotations, thus stabilizing the trunk and COM therefore facilitating the overarching goal of maintaining total body balance and gaze stabilization (Callaghan et al., 1999). The occurrence of some of these trunk rotations are altered in subjects with LBP.

Subjects with LBP have a progression toward an in-phase relationship between the thorax and pelvis in gait at a self-selected gait speed, slow and fast speed (Huang et al. 2011, Lamoth et al., 2004 & 2006; Selles et al., 2001), The trunk displayed less counter rotation related to the pelvis thought to be explained by a more continuous contraction of the lumbar erectors creating a splinting effect of the trunk.

Compressive forces acting on the lumbar spine during gait might produce pain and play a role in the altered gait pattern found in subjects with LBP. Although the loading of the lower segments of the spine is approximately 2.5 times the body weight during normal gait (Hamil & Knutzen, 2003), an increase in gait speed reduces the compressive loads significantly due to less compressive force produced by the trunk muscles (Callaghan et al., 1999). Because of the pelvic inclination and associated lumbar lordosis there is a shear force acting on the lower segments of the spine in an anterior direction when



standing. This force is estimated to be between 24-50% of the body weight in standing and decreases slightly when walking due to the reduction of pelvic inclination (Callaghan et al., 1999; Hamil & Knutzen, 2003). It follows that the rigid body segment seen in subjects with LBP may potentially contribute to increased loads on the lumbar spine and prevent an effective positioning of the pelvis. The casualty is not clear and needs further exploration.

The muscles responsible for balancing and moving the trunk are primarily the erector spinae, multifidus, quadratus lumborum, rectus abdominus and oblique and transverse abdominus (Nordin & Frankel, 2001). A study, widely referenced (Richardson, 1999), illustrates that the task of these muscles to stabilize the trunk during tasks such as rapid arm lifts requires anticipatory contractions which may be altered in individuals with LBP. During a rapid arm lift movement delayed onset was found of transverse abdominus (TrA) and internal oblique (IO), where the same muscles in the healthy controls demonstrated onset of activity in advance of postural perturbation demonstrating a “feed-forward” mechanism thought to stabilize the spine.

It is reasonable to hypothesize that a similar feed-forward mechanism exists during gait in order to stabilize the trunk. One study of healthy subjects (Nordin & Frankel, 2001) demonstrated that just before heel strike there is a moderate electromyographic (EMG) burst of activity in longissimus and multifidus on the ipsilateral side suggesting a feed-forward mechanism preparing the trunk to

adapt to the change in weight distribution followed by an even larger burst of activity in the contra-lateral longissimus, erector spine and multifidus at heel strike itself. These lumbar extensor muscles work in synergy with the pelvic stabilizers, especially gluteus medius, in order to elevate the contra-lateral pelvis allowing for floor clearance of the swing leg. The rectus abdominus and oblique abdominal muscles' action during gait is to stabilize the trunk and provide a slight forward flexion moment assisting in the forward translation of the body weight. In accord with Richardson (1999) there are other studies that point to an altered muscle recruitment pattern in the trunk during gait in individuals with LBP (Lamoth et al., 2004 & 2006): Lamoth et al. examined the muscle activation pattern via surface electro-myography (EMG) and found the muscle activation pattern of the erector spine (ES) showed an earlier onset and prolonged contraction during the gait cycle as well as increased variability of muscle contractions across speeds. In other words, the individuals had difficulties adjusting to the perturbation introduced by the sudden speed changes. In contrast Taylor et al. (2003) found that subjects with acute low back pain were able to tolerate an increase in walking speed to 40% above their preferred speed without increased pain. What's more surprising is that the subjects with acute pain, not chronic pain, demonstrated the same change of gait characteristics as their age-matched healthy controls. It can be hypothesized that the subjects with acute LBP did not show the same rigid body

segments as found in subjects with chronic low back pain because of a time factor. It is possible that the muscle activation patterns found in healthy subjects were preserved in the acute stage of an episode of LBP, but eventually progress to include change in activation patterns. In an attempt to investigate the effects of the presence of pain, Arendt-Nielsen et al. (1995) compared subjects with chronic low back pain to a group of healthy individuals before and after receiving experimental low back muscle pain via a saline injection. Once experiencing the experimental pain, the healthy subjects demonstrated an alteration of the muscle pattern that was identical to that experienced by the subjects with chronic low back pain. There were an increase of peak contractions in the lumbar erectors during the swing phase and a decrease of peak contractions during double stance phase (Table 1). The authors hypothesized that the pain prevented an effective contraction during the stance phase. This is thought to be due to a protective reflex inhibition explained by a reduced ability to contract the muscle in the presence of pain. Furthermore, the authors reported an increase of the EMG activity during the normally relative silent swing phase evidencing an increased excitatory state of the local neuromuscular system.

In a similar experimental clinical, trial Lamothe et al. (2004) also induced experimental pain in healthy subjects and investigated its effect on walking. The only significant change was an increase of variability of EMG patterns of erector spine both during swing and stance phase. Further support for the finding of

altered activation of lumbar muscles during gait in individuals with chronic or recurrent LBP were found in a study by Vogt et al. (2003). Their study examined 16 individuals with current LBP and 16 matched controls during walking at self-selected gait speed. EMG capture of selected muscles demonstrated an earlier onset of EMG activity in ES, gluteus maximus (GM), and hamstring muscles compared to the healthy controls. The prolonged activation of LE and GM coupled with the slower self-selected gait speed and lesser hip joint excursion was interpreted as an indication of change of the neuromuscular control of the pelvis and trunk muscles. The prolonged muscle activation may have served to stabilize the lumbar spine in an attempt to prevent further pain or destabilization of the trunk.

In summary, subjects with LBP have an alteration of the trunk and pelvis relationship during gait with the normal out-of-phase relationship changed to a more in-phase relationship, or rigid body segments. Prolonged muscle activation, especially of the lumbar erectors, could explain the occurrence of the in-phase relationship due to a shift of muscle activation from a dynamic, variable and asymmetrical pattern to a more symmetrical and static pattern which would facilitate a more rigid body segment such as the one found in subjects with LBP. It is not clear how the prolonged activation of the erector spine affect the pelvic inclination but it is plausible it would increase the lordosis which would not allow for the load reduction of the lumbar spine experienced by healthy subjects, who

reduce their pelvic inclination thereby reducing the anterior shear force. It also remains unclear why this rigid body strategy is occurring as the mobility of the lumbar spine is not challenged during normal gait and the loads experienced are only moderate, and even lessen with faster gait speeds. It leaves the question if guarding the spine during gait in the presence of LBP is a strategy adopted out of anticipation of pain or a function of increased excitability of the lumbar neuromuscular system in presence of pain.

#### Sit to stand and LBP

Rising from a seated position is an everyday activity that is performed multiple times a day, such as when standing up to walk, standing up to get something or standing up to get a better view. Since, while seated approximately 85% of the body is supported by the seat to complete the task of rising from a seat requires concerted movements and balancing of body segments (Hirschfeld et al., 1999). Seat height, foot positioning, arm rest availability, selected speed and whether the motion stops at standing or continues into walking change the requirement of the lumbar spine and lower extremity with regards to movement characteristics, speeds and moments placed through the feet (Janssen et al., 2002).

The sit-to-stand (STS) movement requires an individual to successfully move the center of mass (COM) over one base of support (BOS), initially the seat, to another BOS defined by the feet (Schenkman et al., 1990; Schumway-Cook & Woollacott, 1995). In addition to the forward movement of the COM over the BOS, the subject has to increase the distance between the COM and BOS to become fully erect (Schenkman et al., 1990).

The STS task is described by Schenkman to consist of four phases:

(1) The flexion-momentum phase is characterized by a forward momentum induced by moving the trunk and pelvis forward. (2) The momentum-transfer phase starts when the buttocks lift off from the surface. (3) The extension phase is characterized by an extension of the hip joints. (4) The stabilizing phase follows once the hip has stopped moving and the subject is fully standing.

During the STS healthy individuals first flexed their trunk (Hirschfeld et al., 1999; Sheppard, 1994) followed by a contraction by the lumbar paraspinals. The purpose of this contraction is thought to be to apply a braking force controlling the forward momentum build by the lumbar flexion (Hirschfeld et al., 1999). After the trunk flexion the pelvis was rotated forward, followed by knee extension, followed by hip extension (Goulart and Vall-Sole, 1999) followed by ankle dorsi flexion (Sheppard, 1994). Due to the need for coordinated trunk and extremity movements, it could be suspected that individuals with LBP may demonstrate similar changes in their movement strategies as seen in studies of

gait, i.e., prolonged lumbar muscle contractions; however, only a few studies exist of the STS movement in a population with LBP.

Shum et al. (2005 & 2009) reported that contribution of lumbar spine motion during the preparatory flexion-momentum phase and momentum-transfer rise phase is reduced in subjects with LBP as is their phase relationship with the hip joints. Furthermore, Shum et al. (2005 & 2009) found hip joint movement and lumbar spine flexion was slower with a later onset than the healthy control subjects. So, although the authors did not report prolonged contraction of the lumbar erectors, an alteration was detected in reduced inclination to move the spine and contract the lumbar musculature. In other words, the contribution of the trunk to complete the STS movement was less. The resulting effect of such dysfunction can be explained by other findings in their study (Shum et al., 2009) demonstrating an altered passive power flow in the pelvis and lower extremity segments in subjects with LBP resulting in a significant increase of work done by the lower extremities.

Because passive forces plays a significant role in the power transfer from the trunk to the lower extremities during the STS, the authors conclude that the STS strategy found in individuals with LBP was ineffective and may introduce a risk for strain and pain in the lumbar spine (Shum et al., 2009). This appears as a reasonable hypothesis considering Panjabi's' model for spine stability (Panjabi, 1992) – that in presence of an increased demand for spinal stability,

the muscles, shown to have an altered activation pattern, may not be capable of assisting the required motion while ensuring segmental stability. This could cause an unstable lumbar spine with risk of pain and possible outright injury.

### Forward bending and LBP

Bending forward is a task performed many times a day, such as when bending to tie a shoe, pick up an object from the floor or reach for a low drawer or shelf. During such forward bending there is a reduction of muscle activity at the peak of the bending motion. This is the so-called “flexion relaxation phenomenon” (FRP), which is explained as follows: In healthy individuals the lumbar extensor muscles will almost completely relax once the individual has bent fully forward (Colloca and Hinrichs, 2005). The occurrence of this phenomenon was evidenced in a study by Olson et al. (2006) that demonstrated the presence of the FRP in 13 healthy subjects performing repeated forward bend in a standing position. Olson et al. (2006) concluded that the muscle relaxation occurring in the healthy individual was gravity dependent and factors as descending vestibular control may play a significant role in inhibiting or stimulating muscle activity. Watson et al. (1997) investigating the EMG activity in subjects with chronic low back pain and healthy control subjects.



The authors found an abolishment of the FRP in subjects with chronic LBP during a repeated forward-bending task. This prolonged activation of the lumbar muscles is similar to the alteration of muscle activation found during gait in subjects with LBP. It is possible that this is a protective mechanism attempting to guard the spine against destabilization.

#### Motor control and Neurophysiologic changes in LBP

In healthy individuals the areas of the brain ascribed specific functions are relatively well identified thanks to, among others imaging studies (Tsao et al., 2008). In individuals with pathologies changes have been reported though. Flor et al. (1997) studied magnetic fields of the contra-lateral brain hemisphere: A painful stimulus was induced at both the side of the low back presenting pain in individuals with chronic LBP and matched controls. A medial shift of the cortical representation of the back stimulation was present in the subjects with LBP suggested occupation of an area normally dedicated to the foot and leg. Furthermore, duration of the LBP was correlated with increased cortical responsiveness suggesting the somatosensory center being reactive at an earlier point in the presence of longer duration of LBP. Another study (Haavik-Taylor and Murphy, 2007) also provide evidence of neurophysiologic changes

in the presence of pain, though in this case patients with neck pain was examined. Somatosensory evoked potentials (SEP) in subjects with neck pain (N=24) were statistically different following spinal mobilization of dysfunctional cervical spinal segments. The subjects receiving a cervical spinal mobilization demonstrated a significant reduction of nerve amplitudes following the SEP after the intervention whereas the control group demonstrated no significant change. Although the study examined a population with neck pain it suggests a similar mechanism may exist for other levels of the spine, namely the lumbar spine.

Tsao et al. (2008) studied 11 individuals with recurrent LBP and 11 matched controls that showed a cortical representation of the transverse abdominus muscle (TrA) that were more lateral and posterior when examined by Trans-cranial Magnetic Stimulation. TrA activation was also examined with EMG during a single rapid arm movement. A map of the cortical representation of the TrA was larger and correlated to TrA response during the rapid arm movement. Delayed onset of TrA activity across subjects with LBP correlated positively with an increased size of the cortical representation of said muscle.

The authors concluded that a reorganization of the trunk muscle representation at the motor cortex was present in individuals with recurrent LBP which could explain the altered postural feed-forward mechanism detected in rapid arm rise tasks (Hodges & Richardson, 1996). In a subsequent study, the same research team (Tsao et al., 2010) found that specific motor control training

targeting the TrA, changed the cortical representation of TrA to a more anterior and medial location in the motor cortex following a three week training protocol. Furthermore TrA contracted more consistently in anticipation to a rapid arm raise, a task previously used in studies investigating postural control (Hodges & Richardson, 1996).

Moseley (2008) in a descriptive study found that six patients with chronic LBP had a different body image than 10 healthy controls. The subjects were asked to draw an image indicating their perceived representation of their trunk. Subjects with LBP had either a missing part correlating with the most painful location of their back or the painful area of their back was drawn smaller. The patients also had a shift of the location of their vertebrae toward their painful side of the trunk. Furthermore, tactile acuity measured with filaments of varied thickness and two-point discrimination sense was reduced in all patients compared to the controls. This indicates there may be an inverse relationship between the sensory representation in the sensory cortex and the related body part.

### Fear avoidance behavior in LBP

Fear avoidance beliefs are identified as an important psychosocial element in individuals with LBP (Fritz et al., 2001). Elevated fear avoidance beliefs about physical activity and pain can lead to a behavior of restricting physical activity during normal daily activities including work. This provides a temporary respite from pain but can lead to a vicious cycle of reduced activity, muscle weakening and psychological effects such as isolation and depression (Telci et al., 2013). Furthermore, elevated levels of FEB have been shown to contribute to the maintenance of LBP (Grottle et al., 2006, Rainville et al., 2011).

### Summary of literature review

The above have illustrated common findings in subjects with LBP. It was demonstrated that subjects with LBP have (1) a change in the phase relationship between pelvis and thorax toward a more in-phase movement of the segments during gait. During gait, ES and GM demonstrated prolonged activity. Furthermore (2) gait speed was found to be reduced with a lesser excursion of the hip joints. Evidence of a (3) prolonged muscle contraction was evident in the alteration of the flexion-relaxation-phenomena (FRP) during

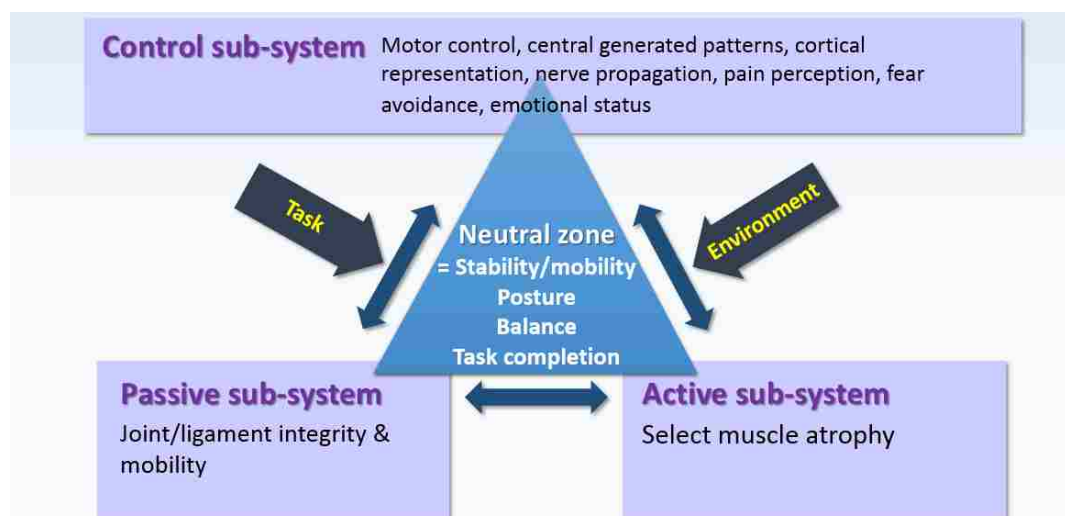
forward bending in subjects with LBP. It is not clear if these changes are muscle activity during gait and forward bending is an attempt to stabilize the spine or a function of the lumbar muscles being more reactive and contracting sooner and longer in individuals with LBP.

Movement strategies (4) were also found to have changed in subjects with LBP who performed the STS task with slower movement of the lumbar spine, later onset of lumbar muscles and decreased efficiency in performing the task. Postural anticipatory control (5) is compromised during standing arm movements with a delayed activation of trunk-stabilizing muscles. Some individuals demonstrate a (6) change of cortical representation of certain trunk muscles. An increase in cortical representation or a migration of this representation toward another region of the brain, as demonstrated in some studies, may lead to movement dysfunction across several functional tasks. The implication of the cortical shift of certain muscles' representation is not explained by these studies, but it is plausible that the lower excitability of an area plays a role in maintenance of a perception of pain. Also this lower threshold could contribute to the early and prolonged lumbar muscle contractions seen in gait and forward bending. Lastly (7) fear avoidance beliefs may contribute to change in movement strategies.

Cause and effect are also not explained in these studies but an interesting link between motor control, cortical representation and neurophysiologic changes has been illuminated (see figure 4).

In summary the common findings in subjects with LBP warranting further research are the following:

- (1) Change in the phase relationship between pelvis and thorax during gait
- (2) Change in gait parameters
- (3) Alteration of the flexion-relaxation-phenomena (FRP)
- (4) Changed movement strategies in sit-to-stand
- (5) Postural anticipatory control compromised
- (6) Change of cortical representation
- (7) Behavioral change



*Figure 4.* Neutral spine in a dynamic system's model. Panjabi's model of the spinal stabilizing system in the context of a dynamic system. Diagram by Kim M. Poulsen.

### Gab in the literature

No studies have examined performance of a stair step down in individuals classified with having lumbar spine instability.

### III. METHODS

#### Institutional Review Board approval

Per Seton Hall University protocol the research project was submitted to Saint Michael's Medical Center's Institutional Review Board, Newark, New Jersey for approval. The project was approved (Appendix A).

#### Study Design

The study was a quasi-experimental with 2 factors, group and side (L/R), and 1 repeated measure (stepping).

#### Recruitment strategy

Subjects self-identified based on reading flyers posted in healthcare clinics and centers and on SHU campus (Appendix B). The PI followed a phone script (Appendix C) to inform the potential subject about the study and perform a basic screening for inclusion/exclusion criteria.



## Subjects

Potential subjects self-identified by calling the principal investigator (PI). The PI performed a phone screen following a standardized script (Appendix C) and send the patient the consent form (Appendix D) and the Modified Oswestry Pain & Disability Questionnaire (Fritz & Irrgang, 2001).

## A Priori Power analysis

A Priori Power Analysis of *Kinematics* of the first 6 subjects in each group were conducted to determine the number of subjects needed (see table 1). With  $\alpha = .05$ , Effect size= .84 and Power = .80 a sample size of 6 was indicated. Then followed a Priori Power Analysis of *EMG* with  $\alpha = .05$ , Effect size= .71 - .86 and Power = .80 indicate sample size of 15. Lastly, a Priori Power Analysis of *Kinetics* (non-sign.) with  $\alpha = .05$ , Effect size= .21 -.60 and Power = .80 indicated a sample size indicated between 8-202 subjects was needed depending on muscle.

Recognizing 202 subjects was not realistic and the EMG and kinematic a Priory Power Analysis both had high effect size and power level it was decided to remain close to those indicators yet go beyond what was indicated. Hence, a decision to include 22 subjects followed (11 in each group).

Table 1

*Demographic Data on Pilot Subjects for a Priory Power Analysis.*

	Age Years (+/-SD)	Height Meters (+/-SD)	Weight Mass kg (+/-SD)	BMI Index (+/-SD)	Leg dominance	Pain Scale mm (+/-SD)	Oswestry Index (+/-SD)
LBP n=6	43 +/- 7.0	1.8 +/- .1	71.7 +/-19.4	25 +/-3.7	Left n=1 Right n=5	17.5 +/-25	4.8 +/-2.7
Control n=6	21.3 +/-1.0	1.7 +/- .1	66.5 +/- 12.4	22.8 +/-1.8	Left n=0 Right n=6	N/A	N/A

Note. N=12

## Inclusion criteria

### *Subjects with LBP:*

- 18 years or older
- Chronic (3 month or more) or recurrent LBP (more than one episode lasting more than 3 months) the past one year and report of one or more of the following symptoms:
  - A feeling of back “giving way” or “giving out”, a need to pop or crack the back, painful locking of back, pain during transitions as sit-to-stand, increased pain returning upright from forward bending, pain with trivial movements, difficulty with unsupported sitting, worse with sustained positions, shorter intervals between bouts of pain, relief with back brace or corset, frequent muscle spasms: All these subjective symptoms found to be predictors of lumbar spine instability (Cook et al., 2006).
- Self-described independent community ambulator.
- Oswestry Pain and Disability score > 20/100

### 1 of 2 clinical tests positive:

- Prone Instability test (see description below)
- Prone Leg Raise test (see description below)

*Subjects without LBP (controls):*

- 18 years or older
- No report of LBP past 1 year
- Self-described independent community ambulator

Exclusion criteria for subjects with LBP:

- One positive lumbar spine instability test

Exclusion criteria for all subjects

- Taking muscle relaxant last one week
- BMI equal to or >30 (= Obesity; NIH, 2012)
- Surgery to spine
- Pregnancy

Dependent variables

- Mean amplitudes sEMG; [% of MVC]
- Onset time sEMG at P3; [sec.]
  - SD above baseline EMG
- ROM b/w trunk & pelvis; [degrees]
- Ground Reaction Force:
  - Force at P3; [N/kg,]
  - Temporal [sec.]

### Independent variables

- Low back pain
- Side (R & L)

### Surface EMG

A Delsys Trigno wireless EMG system (Delsys, Natick, Massachusetts) was used to collect surface EMG signals from the target muscles. The system consists of 8 bipolar 4-silver-bar wireless electrodes with the dimensions of 37 X 27 X 15 mm (length, width, height) containing an internal battery powered transmitter and a remote charge station that also function as a receiver for the sEMG signal. The charge station is connected to the desktop PC containing the capture software used for the data collection and analysis. The electrode captured the signal at 2000HZ and transmitted it wirelessly to the base that again digitally transferred the data unprocessed to the PC.

Electrodes was attached to the skin of the subject with a non-allergenic Delsys double-adhesive interphase following a protocol described below. The location of each electrode follow the guidelines of Noraxon ([www.noraxon.com](http://www.noraxon.com)) and Delsys own guide for electrode placement ([www.delsys.com](http://www.delsys.com)). Care was taken to clean the skin vigorously by rubbing with an alcohol prep-pad to ensure good adhesion and conductivity in addition to place the electrode parallel to the

direction of the muscle fibers per best practice in surface EMG capture (ISEK, 2014, Winter, 1990). Only a couple of subjects needed to have hair removed with a single-use razor at the location of the electrode.

Specific electrode locations (all bilateral):

- Abdomen: 3 cm lateral and 3 cm superior to umbilicus
- Low back: 4 cm lateral to T11
- Gluteus medius: Midpoint and inferior 2 inch of iliac crest
- Calves: Midpoint of vastus medialis of gastrocnemius

Electrode specifications:

- Bandwidth: 20-450HZ
- Sampling frequency: 2000 Hz
- CMRR > 80dB
- Impedance: 10  $\Omega$
- 16 bit EMG signal resolution
- Maximally flat Butterworth filter
- Amplification at base output: 909 X

Once transferred from the base to the desktop computer the EMG data was managed in Qualisys Track Manager Version 2.9, 2013/14 along with the kinematic and kinetic data.

#### EMG signal processing:

Once EMG signal was transferred to V3D a script was applied, courtesy of L. Cabell (2014, personal communication; See Appendix E): The script performed the following processing: A linear envelope was created, the signal was full wave rectified and a low pass Butterworth filter at 3.14 Hz was applied, the latter to remove unwanted ECG signals from the heart (Winter, 1990). Thereafter the signal was normalized (in %) to the MVC collected from the respective muscle.

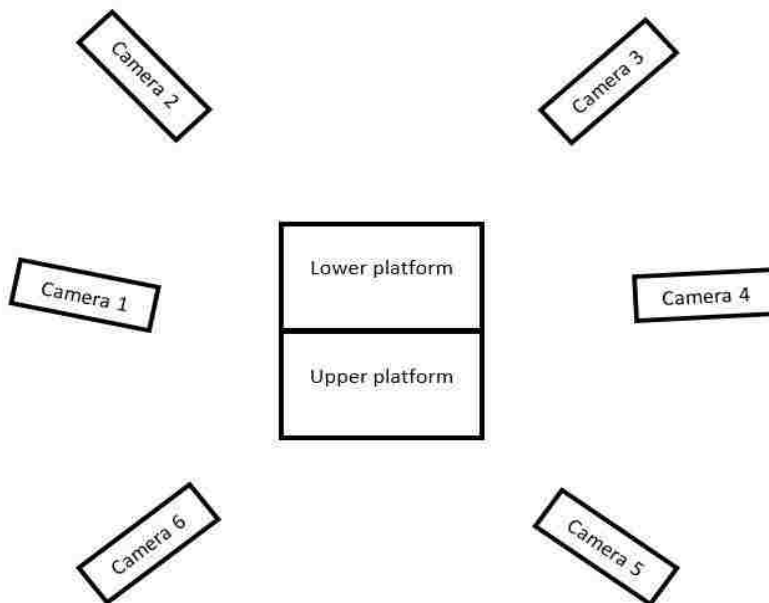
#### Motion capture system

The camera system used to collect kinematic data is Qualisys, Sweden, ProReflex MCU 1000 (6 cameras) with the associated software program Qualisys Motion Capture System (QTM) Version 2.9.

Camera specifications:

- 680 x 500 pixel CCD image sensors = Effective resolution: 20000 x 15000 sub pixels.
- Sampling rate: 100Hz

Cameras were mounted on tripods elevated approximately 7 feet high to ensure good viewing angles and placed around the step platform to effectively cover front, sides and back of the subjects. See figure 5 for camera setup.



*Figure 5. Camera setup.*



### Calibration Procedure

Prior to collecting data on each subject the camera system was calibrated using a standardized length wand with reflective markers and a standardized L-frame with reflectors placed on the upper force plate. During the 30 sec. standard calibration capture the wand was moved at a steady, fast speed. Calibration was only accepted if the error on each of the 6 cameras were less than 1 mm. In a majority of trials the error rates were below .7mm.

### 3D Modeling

Forty-three (43) reflective markers were used to define landmarks in QTM; The location of markers followed Visaul3D's recommendations for placement to model standard body segments. In consultation with engineers at C-Motion the location of trunk markers for this particular study were customized to optimize capture specific to the task the subjects were to perform. All markers in all trials were identified before files were exported to V3D. In a few case an inadequate amount of markers were captured by the camera during parts of the movement trials; In these few cases a gab-fill process were used to predict the path of the marker as the body were in motion to allow identification of a virtual

marker; This allowed for this particular body segment to be modeled once exported to V3D. A minimum of 3 trials for each side (L/R) were digitized and exported to V3D. In a large majority of subjects 4 trials per side were utilized and many had 5 per side. Once data were exported to V3D a rigid body segment model creation process was employed in Visual 3D Professional v.5.01.11, 2014 software (V3-D) (C-Motion Inc.: Rockville, MD). The software use a Direct Linear Transformation (DLT) algorithm (Abdel-Aziz & Karara,1971) to define body segment based on the marker locations identified in QTM. Euler angles was utilized by the software to determine body segments' position and movement as it related to a standard lab coordinate system (Manal & Buchanan, 2004).

Markers were placed as follows to define body segments (see also figure 6 for example of marker placement):

Trunk:

- Sternal notch, acromio-clavicular joints, process of C7 and T10, left and right upper back at mid-point between medial midline of scapula and the spine.

Pelvis:

- Bilat PSIS and midpoint of bilateral iliac crests

Hip joint:

- Trochanter major bilat

Thigh:

- Bilat mid-thigh via a 4-marker rigid shell

Knee joint:

- Lateral and medial knee joint bilat

Shank:

- Bilat shank via a 4-marker rigid shell

Ankle joint:

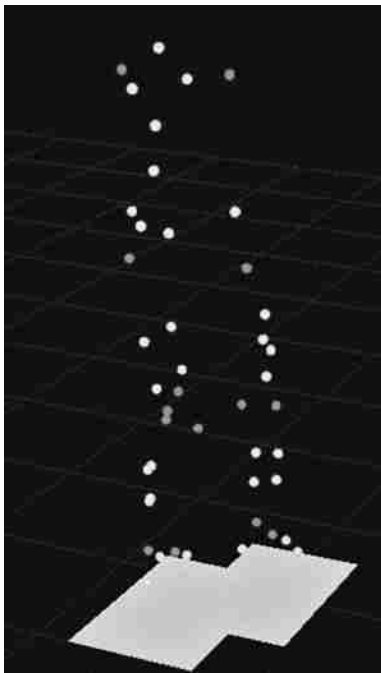
- Bilat lateral and medial malleoli

Foot:

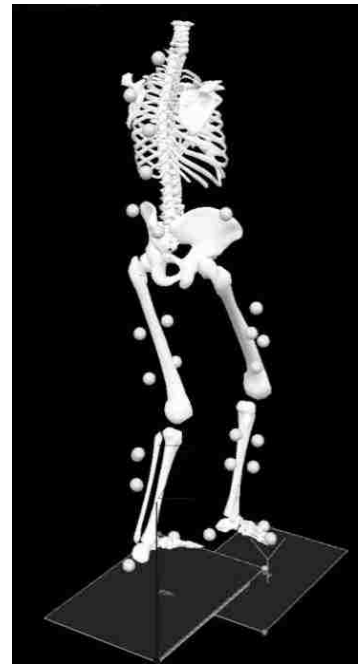
- Metatarsal joint of 1<sup>st</sup> and 5<sup>th</sup> toe bilat and bilat midpoint of posterior calcaneus.

A one-second capture was used to identify the 43 static markers that was exported to the V3-D software where a model is build using a model template. The model template was created in V3-D using a standardized marker placement process to define the trunk as one whole body segment and the pelvis same. The lower extremities were created to allow ease of visual inspection of trials.

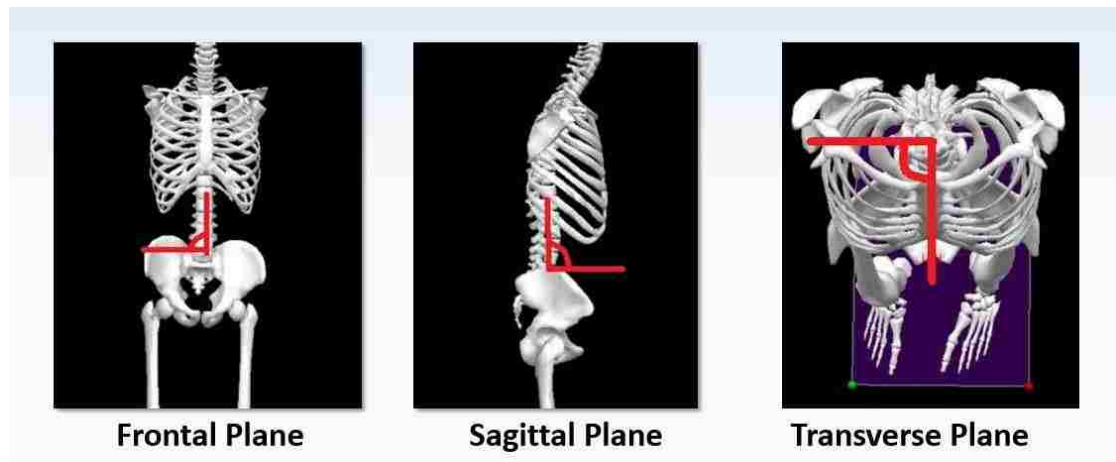
Once the static model was defined (see figure 7) this model template was then applied to subsequent dynamic motion files. From the dynamic motion files trunk kinematics was derived via a report generation. See figure 8 for illustration of the trunk and pelvis relationship used to determine trunk ROM.



*Figure 6.* Markers identified before export.  
Image by Kim M. Poulsen.



*Figure 7.* Finished model.  
Image by Kim M. Poulsen.



*Figure 8.* A 90 degree alignment of the vertical orientation (z axis) of the trunk in relation to the horizontal (x axis) orientation of the pelvis is considered neutral= 0 degrees in the frontal and sagittal plane respectively. A 90 degree alignment of the trunk and pelvis in the y- and x-axis respectively is considered neutral= 0 degrees in the transverse plane. Image by Kim M. Poulsen.

### Force plates

Two force plates used to collect kinetic data: Bertec, Columbus Ohio, Model FP 4060-08. This is a 16-bit signal acquisition system using strain gauge transducers to capture ground reaction forces. The signal captured is analog and via an A/D board the signal it was transferred to QTM in the desktop computer. Ground reaction forces are related to an X-Y-Z coordinate system that correspond with the Y-axis being straight forward (sagittal plane), the X-axis is left to right (frontal plane) and the Z-axis is the vertical axis. The signals

are captured as force in mVolts for each of the 3 directions of X-Y-Z. From this force data and location of the force platform in relation to the lab coordinate system the COP is then calculated in V3D. Only the vertical Z-force is calculated.

As seen in illustration below the 2 force plates are imbedded into platforms creating a 9.5 inch step (Figure 9).

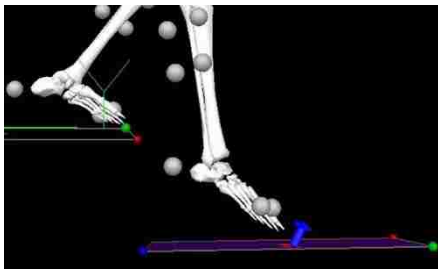


*Figure 9.* Platform setup with force plates imbedded and a model demonstrating the step task. Note the reflective marker placement. Image by Kim M. Poulsen.

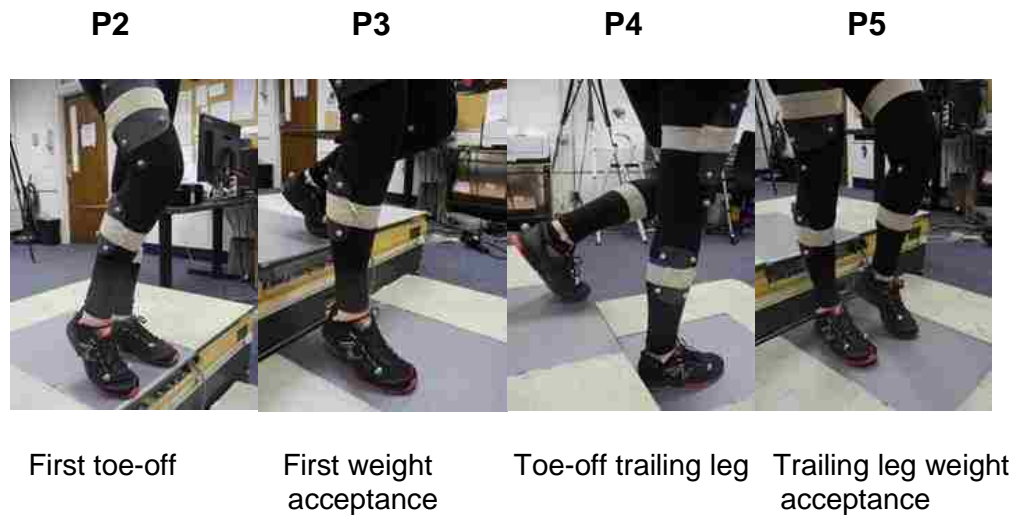
## Trial Phases

The steps trails are analyzed utilizing phases of the step. The phases are defined by events as follows (see picture 10 and 11 below):

- Phase 1: Between start of data collection (P1) and first toe off (P2). Data from phase 1 is not used for analysis and not displayed in figure 12.
- Phase 2: Between first toe off (P2) and first weight acceptance (P3)
- Phase 3: Between first toe off (P3) and second toe off (P4)
- Phase 4: Between second toe off (P4) and second weight acceptance (P5)



*Figure 10.* Location of P3; Picture of first frame captured at first weight acceptance. Blue arrow indicate initial force detection. Image by Kim M. Poulsen.



*Figure 11.* Definition of the step events P2-P5 with explanation of event. Image by Kim M. Poulsen.

### Procedure

Upon arrival the subject was awarded a \$10 gift certificate.

Subjects arrived with the consent form signed; and subjects with LBP brought the Modified Oswestry Pain & Disability Questionnaire completed. The PI answered any questions the subject had prior to starting the testing procedures as well as oriented them to the session. If the subject met the inclusion criteria and none of the exclusion criteria and completed the session the subject were awarded an additional \$10. Approximately 4 subjects were excluded based on the phone screening. All subjects included via the phone screening and arriving at the lab completed the session.



### Body height and weight

The subjects were asked to remove footwear in preparation for height and weight measure. The subject was measured for height and weight using a standard tape measure against the wall and a standard electronic floor scale respectively. The so-called Body-Mass Index (BMI) was calculated. All subjects had a BMI < 30. This criteria established to reduce interference and noise resulting in potentially unreliable data as fatty tissue is a poor conductor for electricity and will distort the data (Baars et al., 2006; Nordander et al., 2003).

### Pain assessment

The subjects marked his/her current pain level (if applicable) on a visual analog scale (VAS) (Bijur et al., 2001) on the subject information sheet as well as the pain location on a body diagram on same form.

### Prone Instability Test

Description of the prone instability test: With the subject standing in front of an examination table, at the foot-end, the subject was asked to lean forward to rest the entire trunk on the table with the feet remaining on the floor. The subject would grasp the side of the table for comfort. Next, the PI applied manual pressure on the lumbar spine. An asymptomatic procedure constituted a negative test and the procedure was then considered completed. If the subject reported discomfort the examiner stopped the pressure and asked the subject to lift the feet slightly off the floor while manual pressure was re-applied once legs were elevated: If this action reduced the discomfort the test was considered positive (Hicks et al., 2003). The procedure took less than one minute. Reliability of the prone instability test is reported to have an acceptable kappa =.87 (Hicks et al., 2003). When this test was positive the next test was skipped.

### Passive Lumbar Extension Test

Description of the passive lumbar instability test: With the subject resting prone on the examination table the examiner held the feet of the subject and elevate the legs approximately 30 cm. above the table. A mark on an adjacent

wall indicated the 30 cm level to ensure consistency between subjects. An asymptomatic procedure constituted a negative test whereas discomfort, anticipation- or report thereof was considered a positive test (Kasai et al. 2006). This test has a sensitivity of 84.2% and specificity of 90.4 %. Although a calculation was not provided the authors report a repeat test by another examiner showed same result in all 84 subjects (Kasai et al., 2006) leading the authors to state the test being highly reproducible (=high reliability).

#### Surface EMG preparation (sEMG)

The PI will place skin sensors on the subject on the following locations: The abdomen, low back hips and calves for a total of 8 locations. The preparation for application of skin sensors will be as follows: The site for skin sensor placement will be cleaned with an alcohol prep pad to remove any lotion, grease etc. to ensure proper adhesion and conductivity. If a subject has a lot of hair at the location for a skin sensor hair will be removed with a single-use dry razor. Using a dry-razor is a common medical procedure in conjunction with similar research and events like sports taping, bandaging and taking EKG. The skin sensors will be placed following standardized muscle locations as described by Noraxon ([www.noraxon.com](http://www.noraxon.com)) and ISEK (ISEK, 2012).

### Reflective marker placement

Next, 43 reflective markers was placed on the subject for tracking purposes as described above. The reflective markers adhered to the subject's shoe, shirt and shorts.

### Static capture

With the subject standing still on the upper platform a one second data capture provided a "snapshot" of marker placements. This static capture were used to create the 3D model of the subject as described above.

### Step down trials

Subject stood on a standard 9.5 inch high step (OSHA, 2014); starting with both feet on step, subject stepped down with one foot, then the second foot follows and are placed next to first foot. This is similar to a regular step down from a curb.

*First*, the subject was asked to step down from the step 3 subsequent times for practice. This also served to determine leg dominance: The leg leading on the most trials out of the 3 steps was considered the dominant leg.

*Second*, the subject stepped down 5 times on both right and left side; 10 total with choice of leading randomized. During this task sEMG, kinematic and kinetic data was be collected.

#### Muscle MVC tests

Next the subject performed maximum voluntary contractions (MVC) of the specific muscles examined in this study. During the activity sEMG data was collected. This recording was during the data processing phase used to normalize sEMG data collected during the stepping trials, that is calculating the percentage of a given sEMG recording compared to the maximum voluntary contraction. The procedure for collecting the MVC followed the guidelines by Konrad (2006) and Yang & Winter (1984). The MVCs were calculated based on a linear envelope from second 2 to second 6 to utilize the EMG when the target muscle had reached its maximum contraction. Below follows a description of the specific MVCs

### Abdominal MVC (Rectus Abdominus)

Subject was supine on a standard treatment table with knees straight. While subject was holding his or her hands behind the neck, the subject was asked to lift his/her trunk up in a straight line high enough to clear the shoulder blades off the surface of the table and hold for 6 seconds.

### Lumbar Extensor MVC (Erectors of the Spine)

The subject was prone on a standard examination table with elbows bent and arms elevated to the shoulders. The subject was asked to lift the shoulders and chest off the surface of the table and hold for 6 seconds.

### Hip Abductor MVC (Gluteus Medius)

The subject was side-lying on the examination table with legs straight. The subject will be asked to raise the upper leg and hold the leg against a strap. The subject held the position for 6 seconds.

### Calf MVC

The subject was standing next to an examination table holding on to table. While lifting one foot off the floor the subject performed a heel raise on the stance leg. The heel raise was held for 4 seconds.

### Statistical Analysis

To test the sEMG for reliability an Inter Class Correlation Coefficient (ICC) was utilized.

Power was determined after recruitment of 6 subjects in each group to determine that 22 subjects total was required for a minimum power of .80.

A Two-way Mixed-Design Repeated Measures ANOVA with Alpha= .05 was utilized to analyze results of movement trials.

A Post hoc t-test was utilized for side determination when b/w groups  $p < .05$ . IBM's SPSS version 22 statistical software was used for analysis of the data.

## Subjects

A total of 22 subjects volunteered for the project. All subjects met the inclusion criteria for their respective group (controls, N=11; LBP, N=11) and completed the testing session successfully. For demographic data see table 2 below.

Table 2

*Demographic data all subjects*

	Age Years (+/-SD)	Height Meters (+/-SD)	Weight Mass kg (+/-SD)	BMI Index (+/-SD)	Leg dominance	VAS Pain mm (+/-SD)	Oswestry Index (+/-SD)
LBP n=11	43 +/- 10	1.8 +/- .2	79 +/-20	26 +/-3	Left n=1 Right n=10	26 +/-25	5 +/-2.7
Control n=11	22 +/- 1	1.7 +/- .1	62 +/- 13	22 +/-2	Left n=2 Right n=9		

*Note.* N=22.



## IV. RESULTS

### Normality, Homogeneity, Sphericity

Assumptions were satisfied for normality, homogeneity, sphericity using Box's M, Levine's, Mauchly's on kinematic and EMG data.

### ICC of EMG

The ICC values for the EMG were high with the lowest value of ICC=.756 for EMG 6 in the control group. See table 3 and table 4.

Table 3

#### *ICC values of Trunk Muscle EMG*

EMG 1 Control	EMG 1 LBP	EMG 2 Control	EMG 2 LBP	EMG 3 Control	EMG 3 LBP	EMG 4 Control	EMG 4 LBP
.975	.995	.963	.998	.989	.992	.837	.960

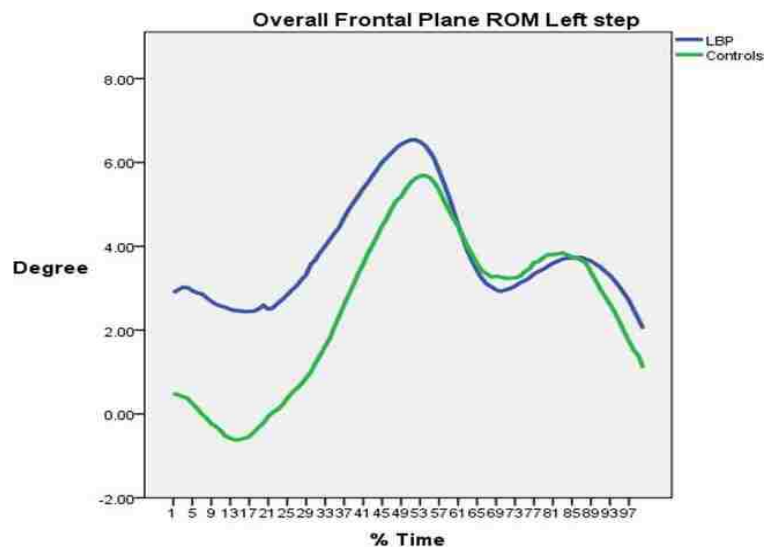
Table 4

#### *ICC values of Lower Extremity Muscle EMG*

EMG 5 Control	EMG 5 LBP	EMG 6 Control	EM 6 LBP	EMG 7 Control	EMG 7 LBP	EMG 8 Control	EMG 8 LBP
.985	.977	.756	.926	.868	.801	.790	.814

### Kinematics Frontal Plane Phase 2-4

Repeated measure ANOVA demonstrated no significance in the full phase 2-4 in the frontal plane regarding within (p=.409, power=.95), between (p=.411, power=.95) or interaction (p=.488, power=.95) between groups. See figure 12 and 13 and table 5.



*Figure 12.* Frontal plane left steps ROM in full step phase events P2 through P5. Phase 3 (double support) is located at peak ROM at approximately 49-64% of step cycle time.

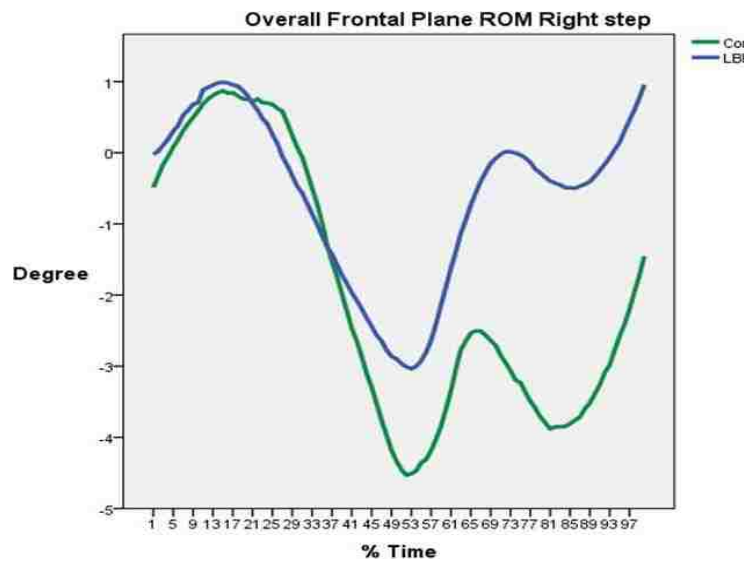


Figure 13. Frontal plane right steps ROM in full step phase events P2 through P5. Phase 3 (double support) is located at lowest peak ROM at approximately 49-64% of step cycle time.

Table 5

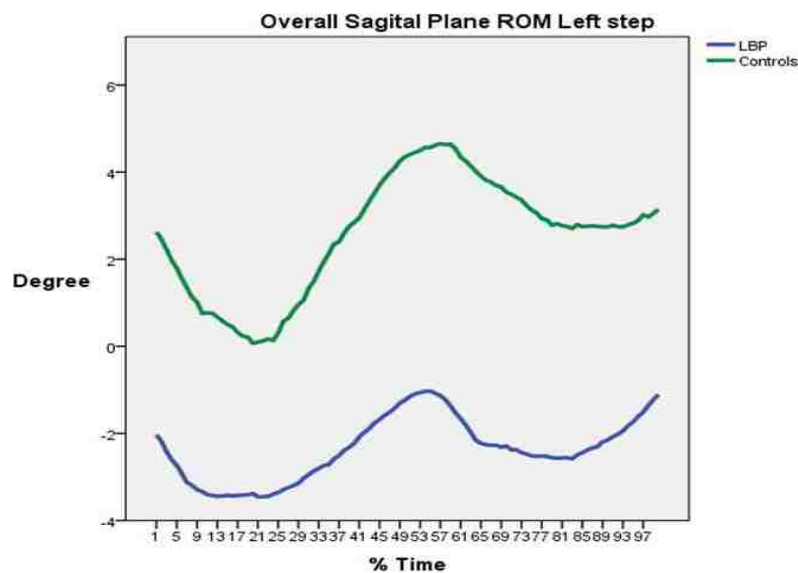
*Trunk ROM Frontal Plane Phase 2-4,*

		<u>Left</u>	<u>Right</u>
LBP	Mean	6.53	6.47
	SD	1.93	2.87
Control	Mean	7.61	6.93
	SD	2.32	2.30

Note. ROM denoted in degrees.

### Kinematics Sagittal Plane Phase 2-4

Repeated measure ANOVA demonstrated significance in the in the full phase 2-4 in the sagittal plane regarding between group difference;  $p=.003$ , power= .99. ROM were less in the LBP group for both Left and Right steps. See figure 14,15 and 16 and table 6.



*Figure 14.* Sagittal plane left steps ROM in full step phase events P2 through P5. Phase 3 (double support) is located at peak ROM at approximately 49-64% of step cycle time.

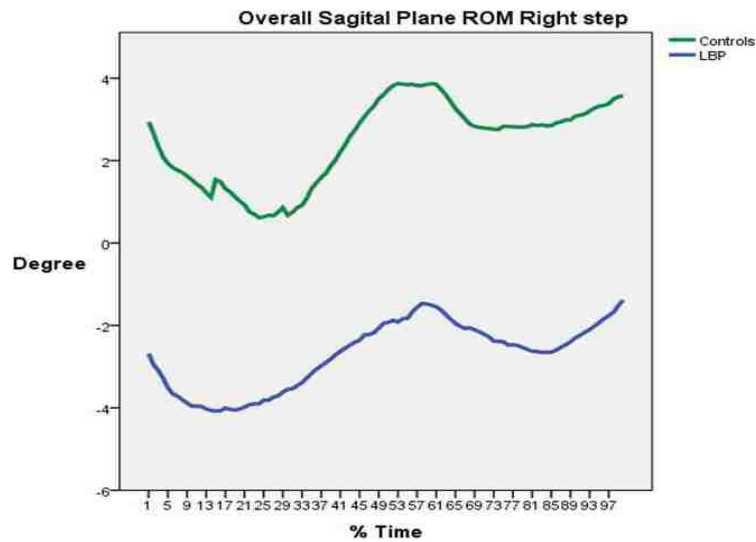


Figure 15. Sagittal plane right steps ROM in full step phase events P2 through P5. Phase 3 (double support) is located at peak ROM at approximately 49-64% of step cycle time.

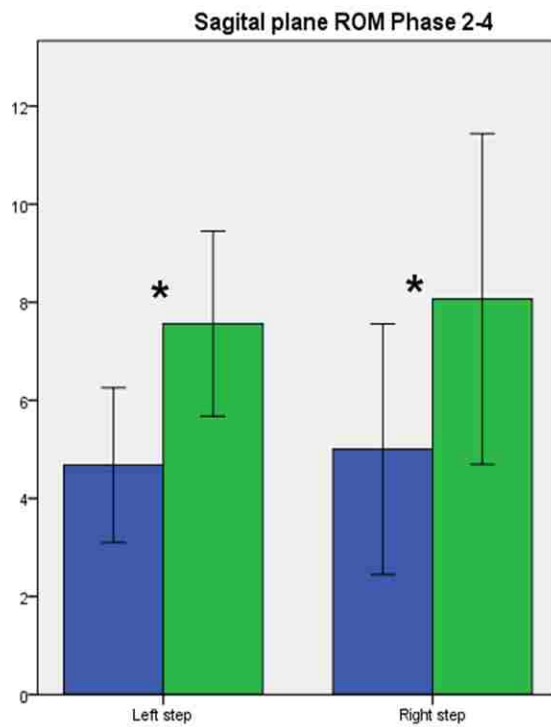
Table 6

*Trunk ROM Sagittal Plane Phase 2-4*

		<u>Left</u>	<u>Right</u>
LBP	Mean	4.68*	5.00*
	SD	1.58	2.56
Control	Mean	7.56*	8.07*
	SD	1.89	3.37

Note. ROM denoted in degrees.

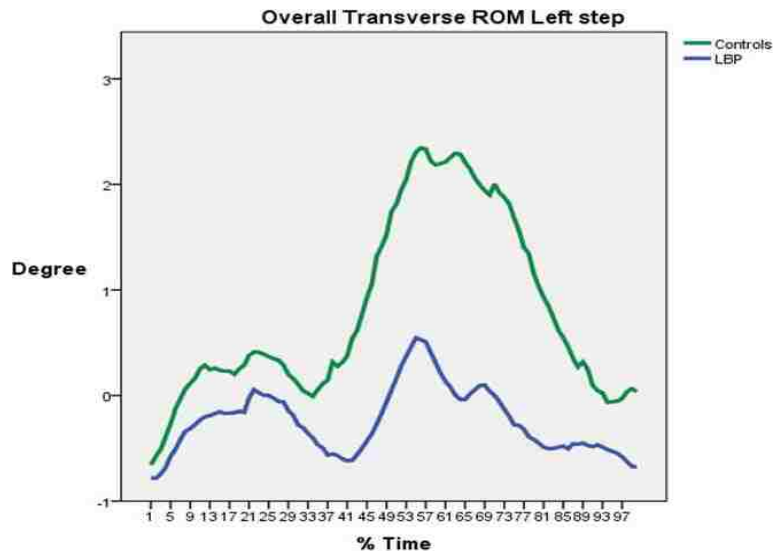
\*Between group:  $P=.003$ , Power=.99



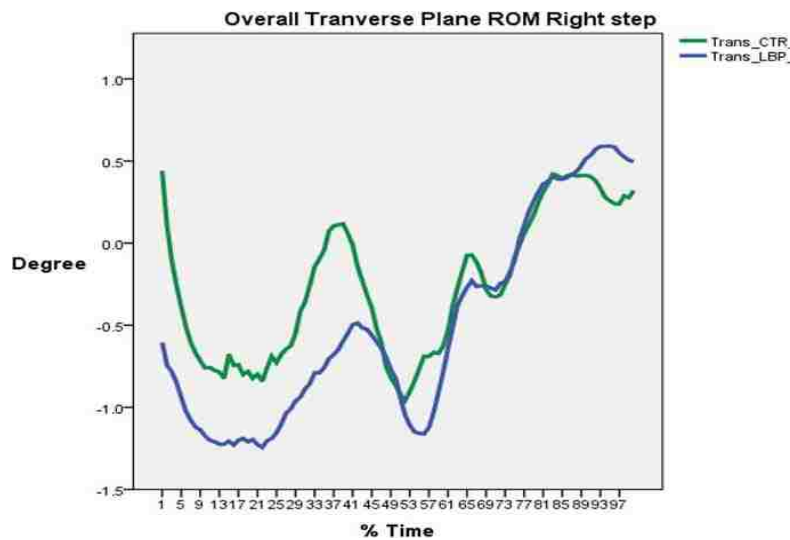
*Figure 16.* Sagittal ROM in degrees in full step phase right and left. LBP group has reduced ROM ( $p < .05$ ).

### Kinematics Transverse Plane Phase 2-4

Repeated measure ANOVA demonstrated no significance in the full phase 2-4 in the transverse plane regarding within ( $p = .51$ , power = .95), between ( $p = .33$ , power = .95) or interaction ( $p = .5$ , power = .95) between groups. See figure 17 and 18 and table 7.



*Figure 17.* Transverse plane left steps ROM in full step phase events P2 through P5. Phase 3 (double support) is located at peak ROM at approximately 49-64% of step cycle time.



*Figure 18.* Transverse plane right steps ROM in full step phase events P2 through P5. Phase 3 (double support) is located at lower peak ROM at approximately 49-64% of step cycle time.

Table 7

*Trunk ROM Transverse Plane Phase 2-4*

		<u>Left</u>	<u>Right</u>
LBP	Mean	3.36	4.31
	SD	1.44	4.59
Control	Mean	4.77	4.77
	SD	2.17	1.30

Note. ROM denoted in degrees.

Kinematics Phase 2

Repeated measure ANOVA demonstrated significance between groups in the sagittal plane on both Left and Right steps as seen in figure19.

Table 8

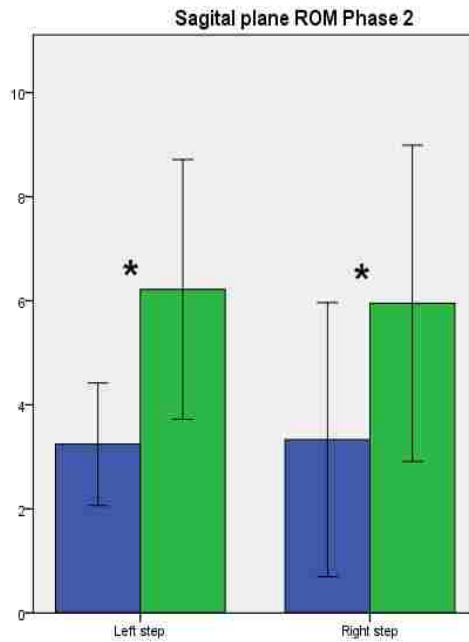
*Trunk Kinematics Phase 2*

		<u>Frontal Plane</u>		<u>Sagittal Plane</u>		<u>Transverse Plane</u>	
		<u>Left</u>	<u>Right</u>	<u>Left</u>	<u>Right</u>	<u>Left</u>	<u>Right</u>
LBP	Mean	4.94	5.26	3.24*	3.33*	2.42*	2.20*
	SD	1.54	2.53	1.18	2.63	1.33	0.71
Control	Mean	6.83	6.24	6.22*	5.95*	3.50*	3.60*
	SD	2.93	2.31	2.50	3.04	1.97	1.12

Note. ROM denoted in degrees.

\*Sagittal plane b/w:  $p=.005$ , power= .99, \*Transverse plane b/w:  $p=.014$ , power= 1.00





*Figure 19.* LBP group (blue) has reduced ROM (degr.) in both left and right steps in phase 2, sagittal plane ( $p < .05$ ).

Repeated measure ANOVA also demonstrated significance between groups in the transverse plane on right steps only as seen in figure 20 below ( $p = .014$ , power = 1.00).

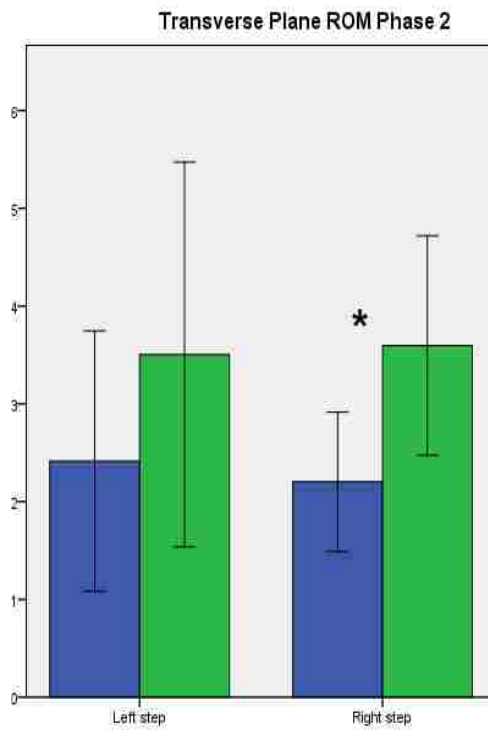


Figure 20. LBP group (blue) has reduced ROM (degrees) in right steps in phase 2, transverse plane ( $p < .05$ ).

### Kinematics Phase 3

No significance found in a repeated measure ANOVA with  $p < .05$  in any of the 3 planes of movement, frontal, sagittal and transverse plane of phase 3.

See table 9.

Table 9

*Trunk Kinematics Phase 3*

		<u>Frontal Plane</u>		<u>Sagittal Plane</u>		<u>Transverse Plane</u>	
		Left	Right	Left	Right	Left	Right
LBP	Mean	3.88	3.38	1.83	2.04	1.88	2.60
	SD	1.96	2.00	0.78	1.38	1.36	3.43
Control	Mean	2.97	2.59	2.98	2.10	1.77	1.78
	SD	1.05	1.34	1.70	1.09	0.67	1.07

Note. ROM denoted in degrees.

Kinematics Phase 4

Repeated measure ANOVA demonstrated significance in the frontal plane on the left side only ( $p=.021$ , power=.99) and transverse plane on the left side only ( $p=.018$ , power=.99) but not in the sagittal plane. See table 10 and figure 21.

Table 10

*Trunk Kinematics Phase 4*

		<u>Frontal Plane</u>		<u>Sagittal Plane</u>		<u>Transverse Plane</u>	
		Left	Right	Left	Right	Left	Right
LBP	Mean	2.78*	3.08	3.23	3.28	1.77*	2.56
	SD	1.40	1.41	1.67	1.80	0.88	1.41
Control	Mean	4.10*	4.07	3.83	4.07	3.15*	3.22
	SD	1.41	1.27	1.69	2.45	1.13	0.92

Note. ROM denoted in degrees.

\*Frontal plane b/w:  $p=.021$  power=.99, \*Transverse Plane b/w:  $p=.018$  power=.99

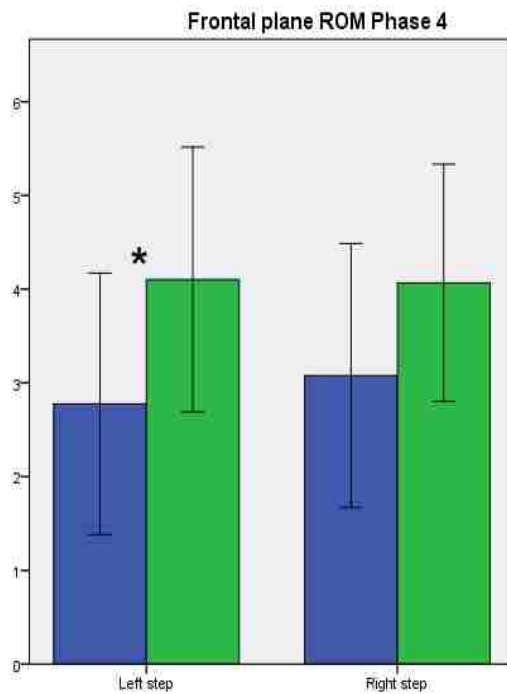


Figure 21. LBP group (blue) has reduced ROM (degrees) in left steps in frontal plane, phase 4, ( $p < .05$ ).

### Kinetics

A repeated measure ANOVA demonstrated the Z-force rise to first peak at P3 (first weight acceptance) to be slower in the LBP group when leading with the left leg ( $p = .016$ , power = .99); See table 11 and figure 22 and 23.

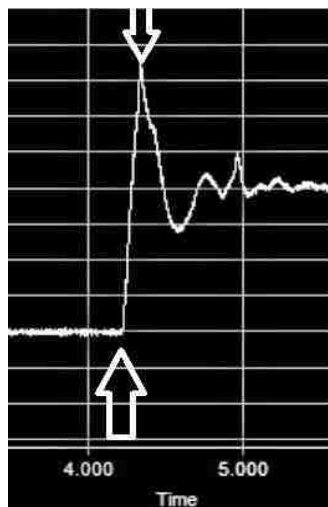
Table 11

*GRF Rise Time to First Peak*

		<u>Left</u>	<u>Right</u>
LBP	Mean	12.74*	12.86
	SD	1.95	1.515
Controls	Mean	10.15	11.42
	SD	1.90	1.63

*Note.* Z-GRF rise time to first peak in sec.  
at first weight acceptance (P3).

\*Between group;  $p=.016$ , power= .99



*Figure 22.* Sample Z-GRF force rise to first peak. Arrows indicate (1) P3 event and (2) first peak of GRF. Image by Kim M. Poulsen.

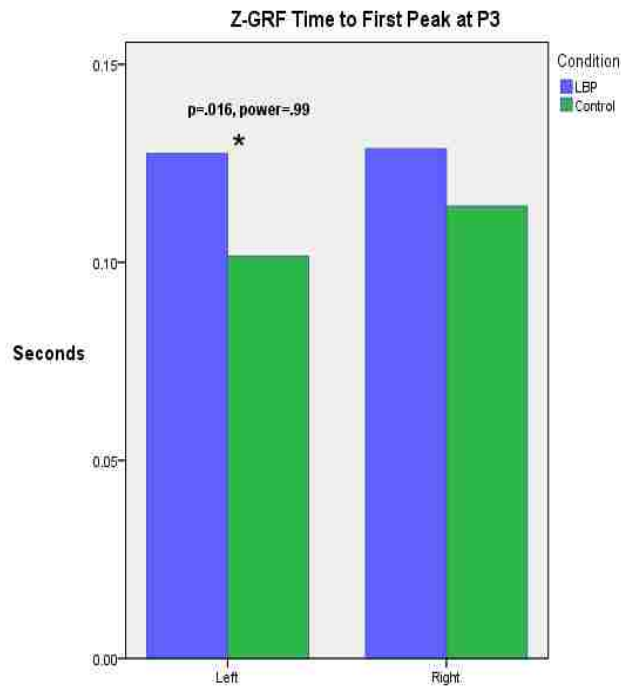


Figure 23. The LBP group has slower GRF rise time on left steps only.

Repeated measure ANOVA did not demonstrate significance at P3 for the amplitude of the GRF Z-force ( $p=.638$ ,  $F=.230$ ). See table 12.

Table 12

*Ground Reaction Force at P3*

		Mean	SD +/-
Left	LBP	14.86	3.25
	Controls	15.62	1.45
Right	LBP	15.25	3.37
	Controls	15.53	1.40

Note. Z-GRF at first weight acceptance in N/kg

## EMG Onsets

### Trunk EMG onset at P3

In the LBP group EMG 2 has delayed onset with Left stepping ( $p=.008$ ,  $power=.91$ ) and EMG 3 has delayed onset with Right stepping compared to the control group ( $p=.025$ ,  $power=.93$ ). In the LBP group EMG 3 has delayed onset with Right stepping but earlier with Left stepping ( $p=.025$ ,  $power.93$ ). See table 13 and figures 24-27 below.

Table 13

### *Trunk Muscle EMG Onset Time at P3*

		EMG 1		EMG 2		EMG 3		EMG 4	
		<u>Left</u>	<u>Right</u>	<u>Left</u>	<u>Right</u>	<u>Left</u>	<u>Right</u>	<u>Left</u>	<u>Right</u>
LBP	Mean	0.396	0.364	0.245*	0.326*	0.132	0.123*	0.152	0.2560
	SD	0.161	0.135	0.160	0.078	0.0535	0.196	0.055	0.172
Control	Mean	0.352	0.368	0.420*	0.294*	0.121	0.301*	0.229	0.302
	SD	0.116	0.061	0.089	0.102	0.080	0.211	0.191	0.168

*Note.* Results are in seconds just prior to first weight acceptance.

\*EMG 2, Interaction;  $p=.008$ ,  $power=.91$ , \*EMG 3, Interaction;  $p=.025$ ,  $power.93$ , \*EMG 3, Between;  $p=.029$ ,  $power.99$ , \*EMG 3, Within;  $p=.016$ ,  $power =.99$

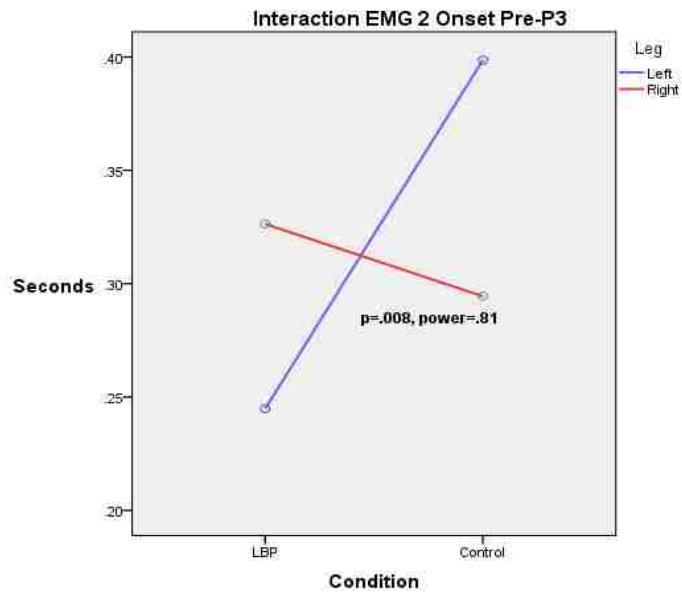


Figure 24. The two groups demonstrate different left abdominal muscle onset time in left versus right steps.

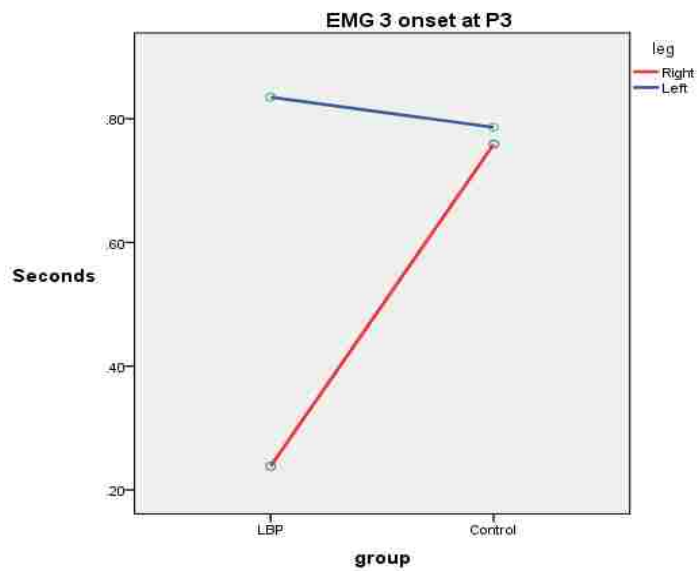
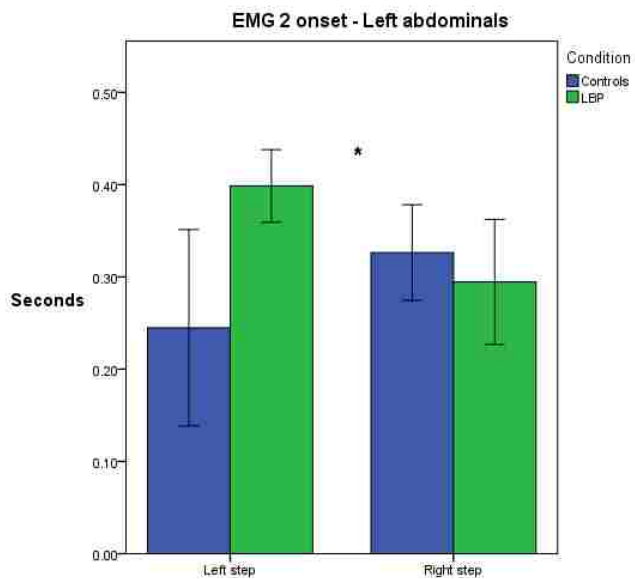
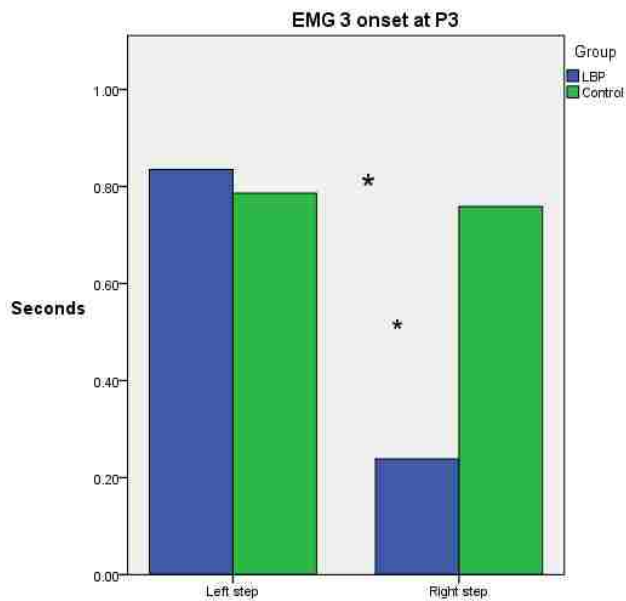


Figure 25. The two groups demonstrate different right lumbar extensor muscle onset time in left versus right steps ( $p < .05$ ).





*Figure 26.* The onset of left abdominals demonstrate reversed timing on left and right steps ( $p < .05$ ).



*Figure 27.* EMG 3 has delayed onset with right stepping but earlier with left stepping ( $p = .025$ , power .93).

### Lower extremity EMG onset at P3

EMG 5 has delayed onset in LBP group compared to the controls ( $p=.043$ ,  $power=.99$ ).

EMG 5, 6 and 8 had significance within the groups with left step having earlier onset for EMG 5 ( $p=.000$ ,  $power=1.0$ ) and later onsets in left stepping in EMG 6 ( $p=.000$ ,  $power=1.0$ ) and EMG 8 ( $p=.002$ ,  $power=.99$ ). See table 14 and figure 28-30 below.

Table 14

#### *Lower Extremity Muscle EMG Onset Time at P3*

		EMG 5		EMG 6		EMG 7		EMG 8	
		<u>Left</u>	<u>Right</u>	<u>Left</u>	<u>Right</u>	<u>Left</u>	<u>Right</u>	<u>Left</u>	<u>Right</u>
LBP	Mean	0.493*	0.085*	0.264*	0.549*	0.490	0.438	0.357*	0.604*
	SD	0.110	0.077	0.134	0.134	0.188	0.2190	0.176	0.158
Control	Mean	0.523	0.227*	0.280	0.559	0.455	0.841	0.491	0.569
	SD	0.144	0.134	0.156	0.172	0.161	1.254	0.124	0.100

*Note.* Results are in seconds just prior to first weight acceptance.

\*EMG 5 between  $p=.043$ ,  $power=.99$ , \*EMG 5 within  $p=.000$ ,  $power=1.0$ , \*EMG 6 within;  $p=.000$ ,  $power=1.0$ , \*EMG 8 within;  $p=.002$ ,  $power=.99$

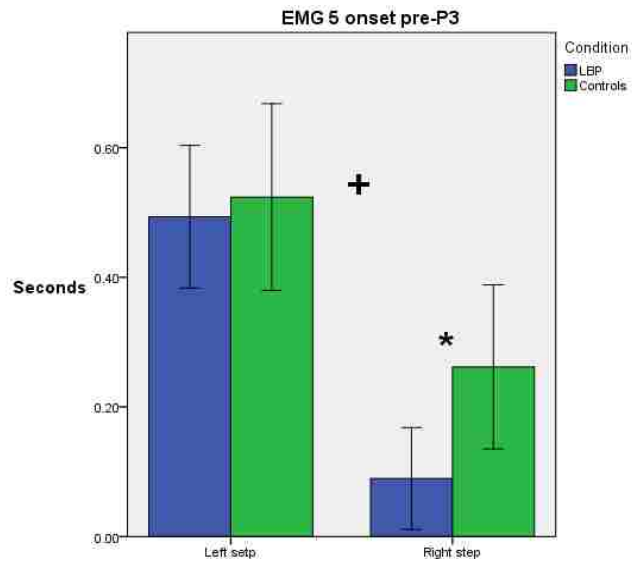


Figure 28. Right hip abductors has delayed onset in right steps and difference within groups ( $p < .05$ ).

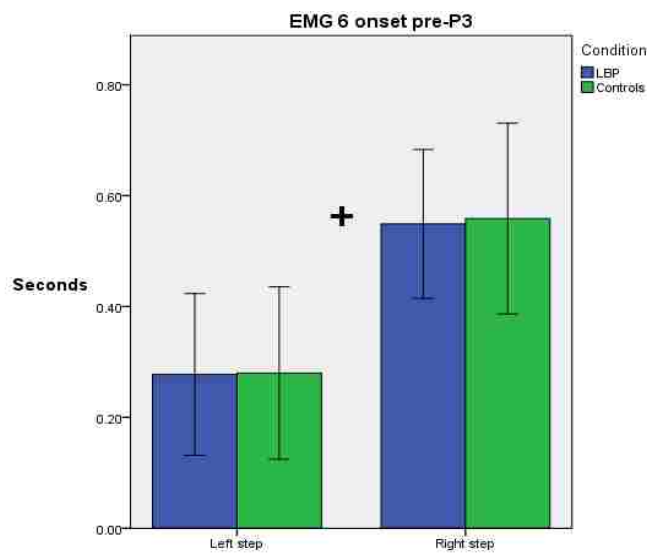


Figure 29. Left hip abductor onset demonstrate difference between left and right steps within groups ( $P < .05$ ).

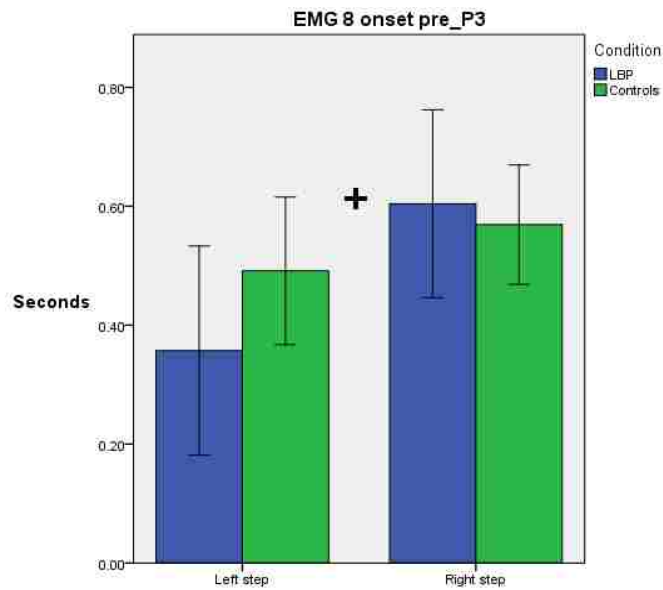


Figure 30. Left calf onset demonstrate difference between left and right steps within groups only ( $P < .05$ ).

## EMG activation phase 2

### Trunk muscle EMG activation phase 2

Repeated measure ANOVA demonstrate significant interaction of EMG 1 ( $p = .045$ , power .6) between groups and as figure 32 shows individuals with LBP has higher activation of EMG 1 in left steps and lower in right steps compared to the control group.

Repeated measure ANOVA demonstrate significance interaction of EMG 2 ( $p=.038$ , power=.62) between groups and as figure 34 shows. Furthermore EMG 2 demonstrate significance within groups ( $p=.03$ , power=.99) in the control group only with higher activity level on left steps and lower on right steps. See figure 33.

Repeated measure ANOVA demonstrate significance between group of EMG 3 ( $p=.047$ , power=.93) with higher activation level in the LBP group in both left and right steps. See figure 35.

Repeated measure ANOVA demonstrate significance within group of EMG 4 on both left and right steps with a t-test having  $p<.05$  on both sides (right:  $p=.026$  & left:  $p=.017$ ). On both sides the subjects have higher activation on right side. See figure 36.

Table 15

*Trunk EMG Activation Level Phase 2*

	EMG 1		EMG 2		EMG 3		EMG 4	
	%MVC +/- SD		%MVC +/- SD		%MVC +/- SD		%MVC +/- SD	
	Left	Right	Left	Right	left	Right	Left	Right
LBP	9.3 *	8.8*	12.3*	12.0*	32.7*	32*	12.1*	13.1*
	± 5.6	± 5.4	± 7.7	± 7.9	+/-23	+/-23	+/-12	+/-11
Controls	6.4	7.4	9.4	8.2	16.1	16.0	4.5	6.2
	± 4.1	± 4.8	± 3.7	± 3.4	+/-7.9	+/-7.9	+/-2.2	+/-3.7

Note.

\*EMG 1 interaction:  $p = .045$ , power = .6, \*EMG 2 interaction:  $p = .038$ , power = .62, \*EMG 2 within:  $p = .03$ , power = .99, \*EMG 3 between:  $p = .047$ , power = .93, \*EMG 4; within:  $p = .046$ , power = .94

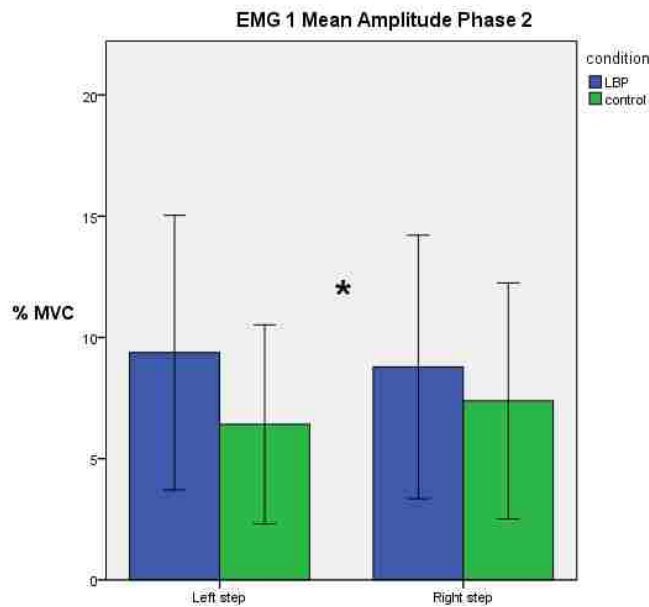


Figure 31. Higher activation of right abdominals is found in phase 2 in both left and right steps ( $p < .05$ ).

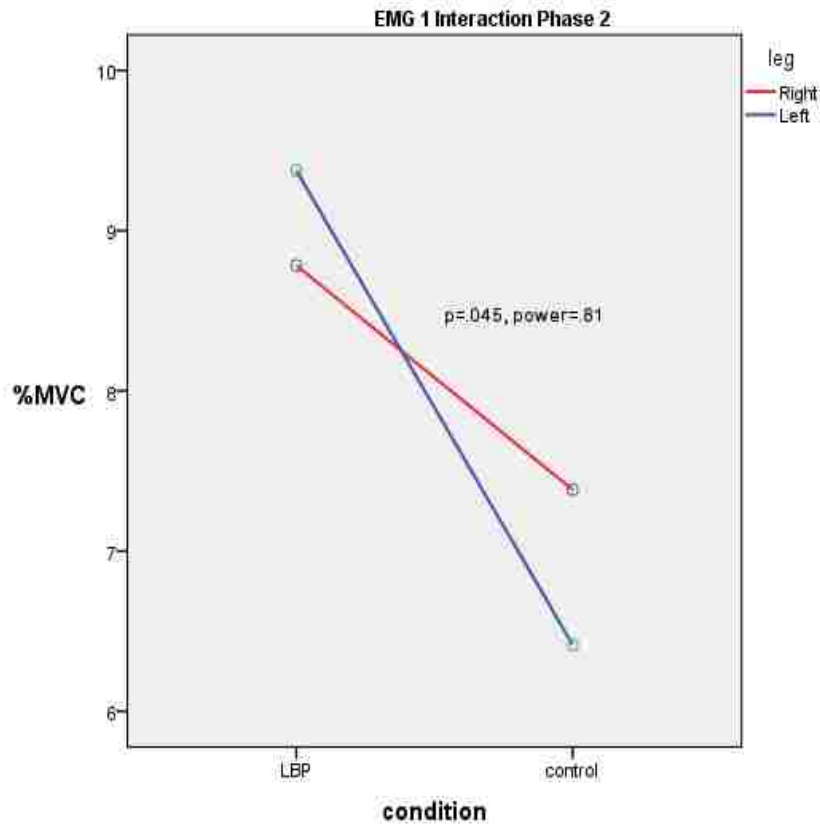


Figure 32. Right abdominals demonstrate different activation levels in left versus right steps ( $p < .05$ ).

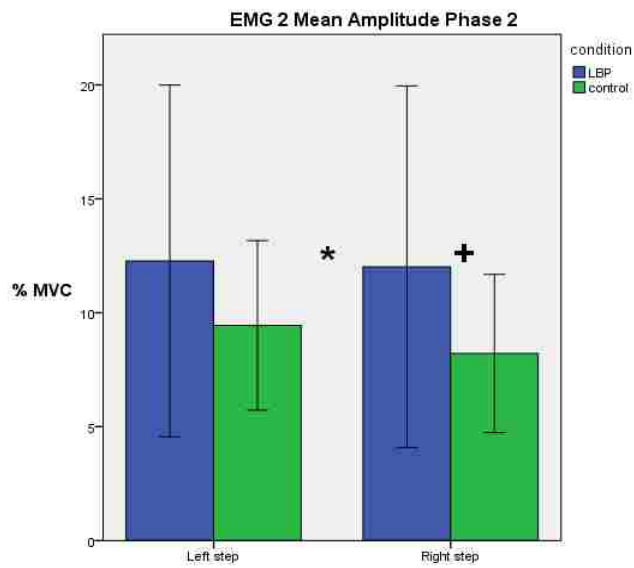


Figure 33. Higher activation of left abdominals in phase 2 in both left and right steps ( $p < .05$ ) as well as difference in activation between left and right steps within groups ( $p < .05$ ).

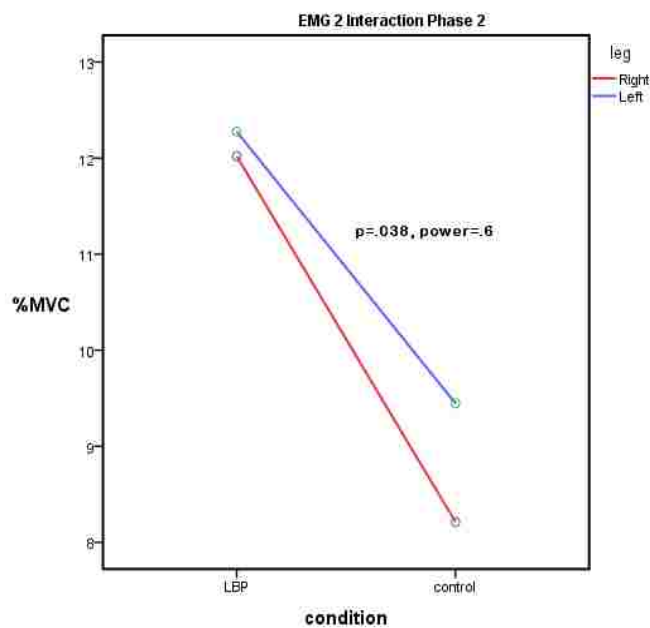


Figure 34. Interaction between groups ( $p < .05$ ) illustrate LBP group activating left abdominals almost equally in left and right steps whereas control group has noticeable different activation levels.



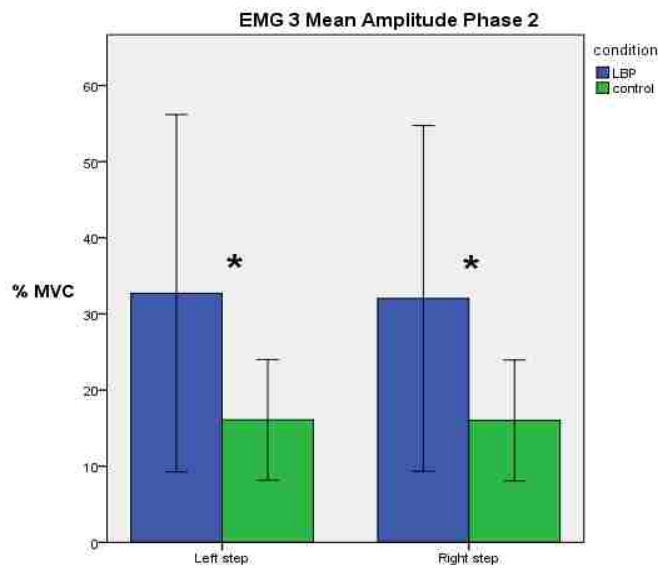


Figure 35. LBP group have higher activation of right lumbar extensors on both left and right steps ( $p < .05$ ).

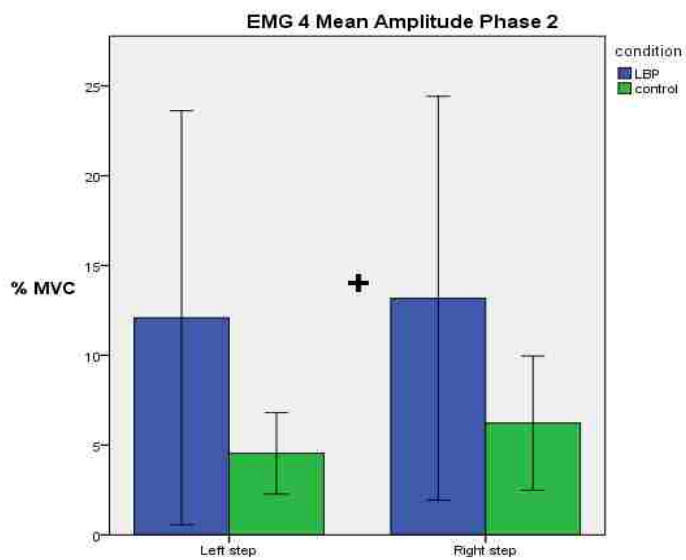


Figure 36. Left lumbar extensors have within group difference in phase 2 ( $p < .05$ ).

### Lower Extremity EMG Activation

Repeated measure ANOVA demonstrate significance between the groups in EMG 5 ( $p = .035$ , power = .96) on right side with the LBP group having higher activation levels. See figure table 16.

Furthermore EMG 5 has significant within group difference ( $p = .011$ , power = .99) with higher activation levels on left steps for both groups. See figure 37.

Repeated measure ANOVA demonstrate significance between the groups in EMG 6 (between;  $p = .017$ , power = .68) with LBP group having higher activation levels then control group on both left and right steps. See figure 38.

Table 16

#### *Lower Extremity EMG Activation Level Phase 2*

	EMG 5		EMG 6		EMG 7		EMG 8	
	%MVC +/- SD		%MVC +/- SD		%MVC +/- SD		%MVC +/- SD	
	Left	Right	Left	Right	left	Right	Left	Right
LBP	55.1	55.2*	25.9	25.9	12.1	26.2	26.5*	9.8*
	+/-20	+/-20	+/-19	+/-14	+/- 6	+/-11	+/-16	+/-5
Controls	39.9	32.2	10.9	14.2	12.0	20.5	18.5*	9.4*
	+/-14	+/-15	+/-6	+/-7	+/- 3	+/-7	+/-5	+/-4

*Note.*

\*EMG 5; within;  $p = .011$ , power = .99; between;  $p = .035$ , power = .96, \*EMG 6; between;  $p = .017$ , power = .68, \*EMG 7; within:  $p = .000$ , power = 1.00, \*EMG 8; within:  $p = .000$ , power = 1.00

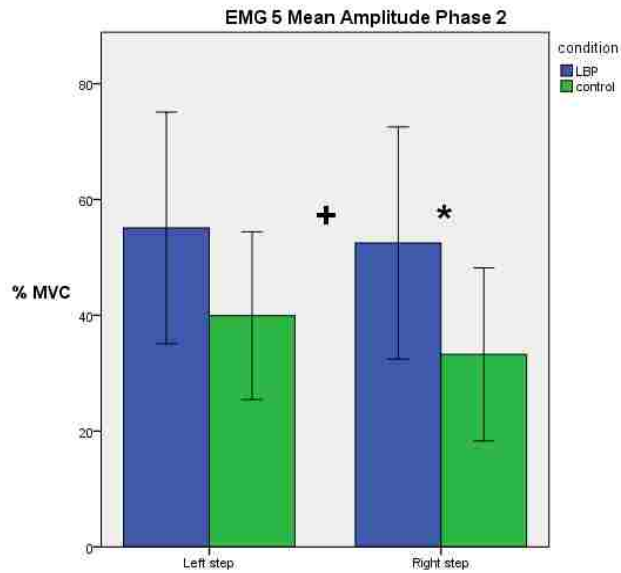


Figure 37. Right hip abductors have higher activation on right steps and groups have within difference between left and right steps ( $p < .05$ ).

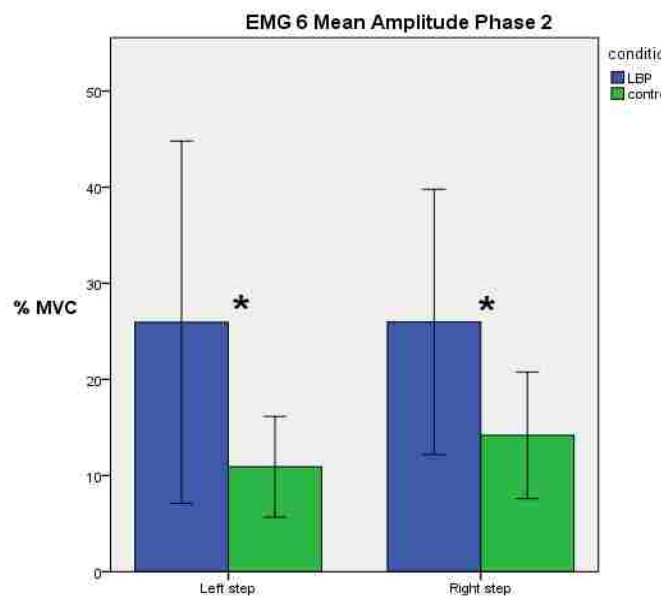
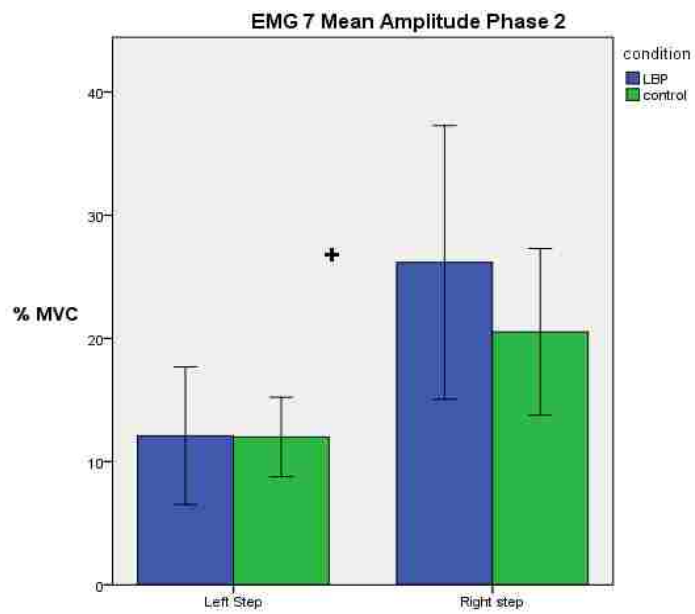


Figure 38. Left hip abductors have higher activation in both left and right steps in phase 2 ( $p < .05$ ).

Repeated measure ANOVA demonstrate within group significance in EMG 7 ( $p = .000$ , power= 1.00) with higher activation on right steps and EMG 8 ( $p = .000$ , power= 1.00) with higher activation on left steps. See figure 39 and 40.



*Figure 39.* Right calf muscle present within group difference between left and right steps ( $p < .05$ ).

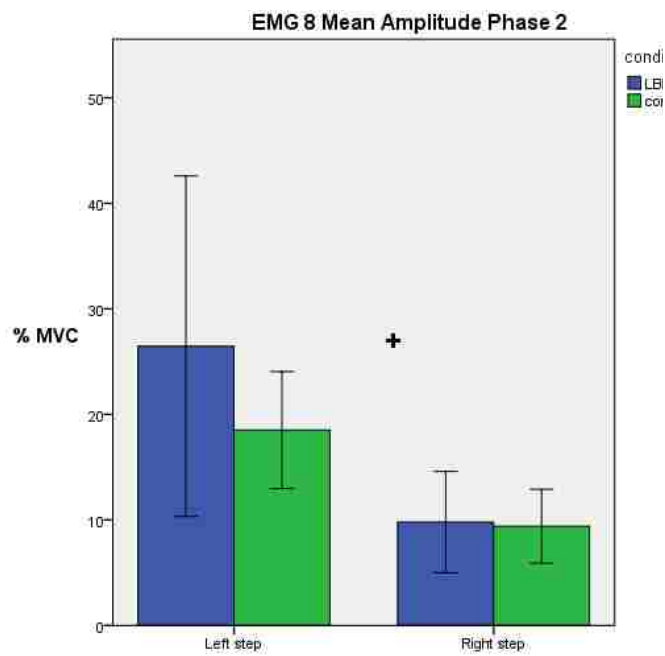


Figure 40. Left calf muscle has within group difference between left and right steps in phase 2 ( $p < .05$ ).

### EMG Activation Phase 3

#### Trunk Muscle EMG Activation Phase 3

In phase 3 the only significance found with a repeated measure ANOVA was in between group difference ( $p = .043$ , power = .94) and a post-hoc t-test demonstrated it to be on right steps only ( $p < .05$ ). See table 17 and figure 41.

Table 17

*Trunk Muscle Activation Level Phase 3*

Group	EMG 1		EMG 2		EMG 3		EMG 4	
	%MVC +/- SD		%MVC +/- SD		%MVC +/- SD		%MVC +/- SD	
	Left	Right	Left	Right	left	Right	Left	Right
LBP	9.5	9.1	12.5	12.2	40.1	37.2*	25.7	25.4
	+/-6	+/-5.8	+/-8.6	+/-8.6	+/-30	+/-24	+/-24	+/-15
Controls	6.5	6.3	9.2	10.0	22.1	16.6	11.3	17.5
	+/-5	+/-4.2	+/-5.8	+/-4.7	+/-12	+/-8.5	+/-16	+/-14

Note.

\*EMG 3; between;  $p=.043$ , power= .94

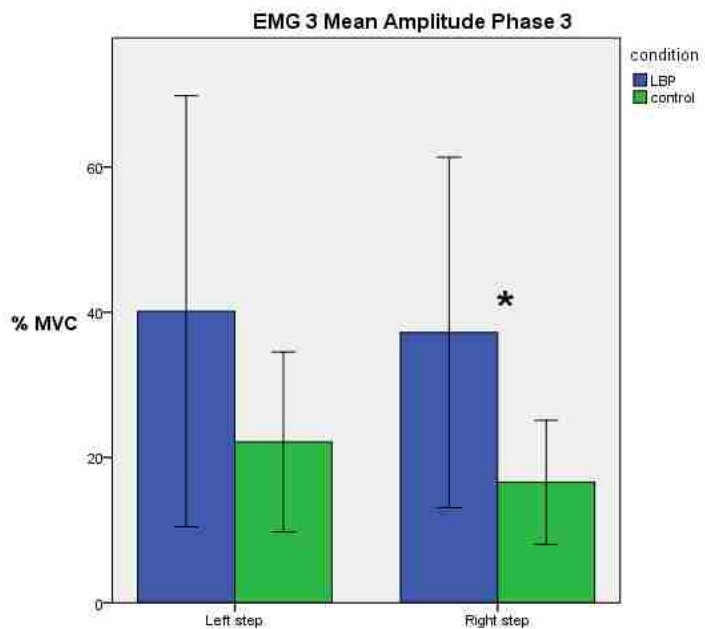


Figure 41. Right lumbar extensors has higher activation in phase 3 (=double support) in right steps ( $p<.05$ ).

### Lower Extremity Muscle EMG Activation Phase 3

Repeated measure ANOVA demonstrated between group significance of EMG 5 ( $p = .042^*$ , power = .94) on left steps with the LBP group having higher activation levels. See figure 42 and table 18. Furthermore EMG 5 showed within group significance ( $p = .001$ , power = .99) with higher activation levels on right steps in both groups.

Repeated measure ANOVA demonstrated significant between group interaction ( $p = .047$ ) for EMG 6 but power is quite low (power = .20). However, between group significance is found with high power ( $p = .024$ , power = .98) with higher activation levels in the LBP group on left steps. See figure 43. Furthermore significant difference is found within groups ( $p = .000$ , power = 1.0) with higher activation on left steps for both groups. Both EMG 7 (figure 44) and EMG 8 (figure 45) demonstrate within group significance ( $p = .000$ , power = 1.00) EMG 7 having higher activation levels on right steps in both groups and EMG 8 higher activation levels on left steps in both groups.

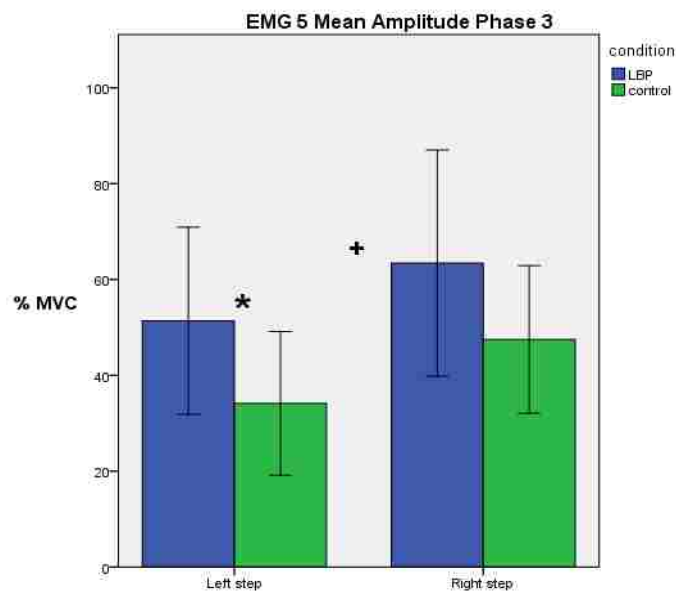
Table 18

*Lower Extremity Muscle Activation Level Phase 3*

Group	EMG 5		EMG 6		EMG 7		EMG 8	
	%MVC +/- SD		%MVC +/- SD		%MVC +/- SD		%MVC +/- SD	
	Left	Right	Left	Right	left	Right	Left	Right
LBP	51.5*	63.4*	65.2	23.6	16.0*	41.5*	39.3*	9.2*
	+/-20	+/-24	+/-41	+/-19	+/-12	+/-13	+/-14	+/-7
Controls	34.1	47.5	31.3	11.4	11.1	34.6	34.0	8.4
	+/-15	+/-15	+/-15	+/-6	+/-4	+/-9	+/-9	+/-3

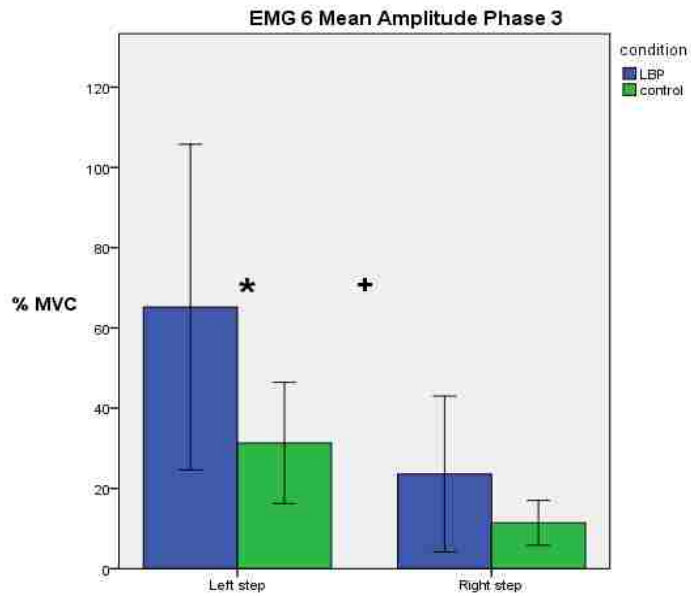
*Note.*

\*EMG 5; between left;  $p = .042^*$ , power = .94, within;  $p = .001$ , power = .99, \*EMG 6: interaction;  $p = .047$ , power = .20, between;  $p = .024$ , power = .98, within;  $p = .000$ , power = 1.0, \*EMG 7; within:  $p = .000$ , power = 1.00, \*EMG 8; within:  $p = .000$ , power = 1.00

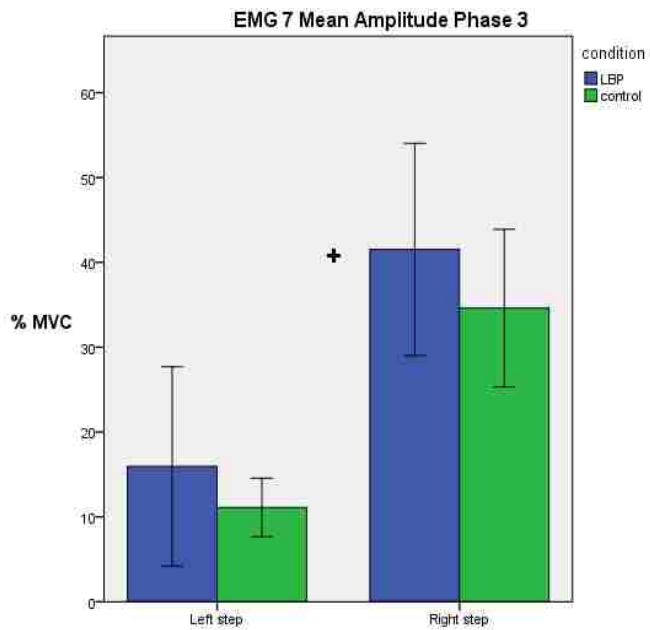


*Figure 42.* Right hip abductors have higher activation in left steps ( $p < .05$ ) and within group difference between left and right steps ( $p < .05$ ).

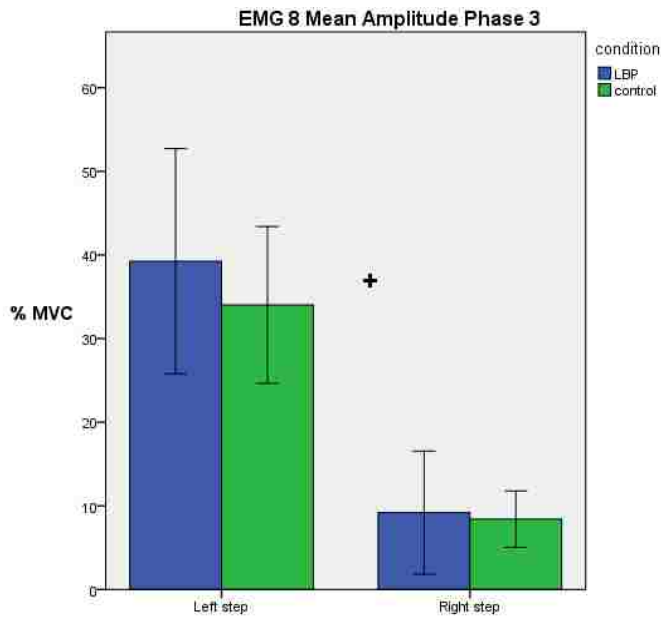




*Figure 43.* Left hip abductors have higher activation in left steps ( $p < .05$ ) and within group difference in left and right steps ( $p < .05$ ).



*Figure 44.* Right calf has within group difference between left and right steps ( $p < .05$ ).



*Figure 45.* Left calf muscle has within group difference in phase 3; double stance ( $p < .05$ ).

#### EMG activation Phase 4

##### Trunk muscle EMG activation phase 4

Repeated measure ANOVA demonstrated within group significance of EMG 4 ( $p = .001$ , power = .96) with higher activation levels on right steps in both groups. See table 19 and figure 46.

Table 19

*Trunk Muscle Activation Level Phase 4*

Phase 4	EMG 1		EMG 2		EMG 3		EMG 4	
	%MVC +/- SD		%MVC +/- SD		%MVC +/- SD		%MVC +/- SD	
Group	Left	Right	Left	Right	left	Right	Left	Right
LBP	8.4	8.4	11.8	11.5	33.7	32.6	13.2*	16.4*
	+/-6	+/-6	+/-8	+/-8	+/-25	+/-24	+/-13	+/-13
Controls	5.1	4.8	7.4	7.5	17.2	15.7	4.9*	9.4*
	+/-4	+/-4	+/-4	+/-4	+/-8	+/-8	+/-2	+/-6

Note.

\*EMG 4; within;  $p = .001$ , power = .96

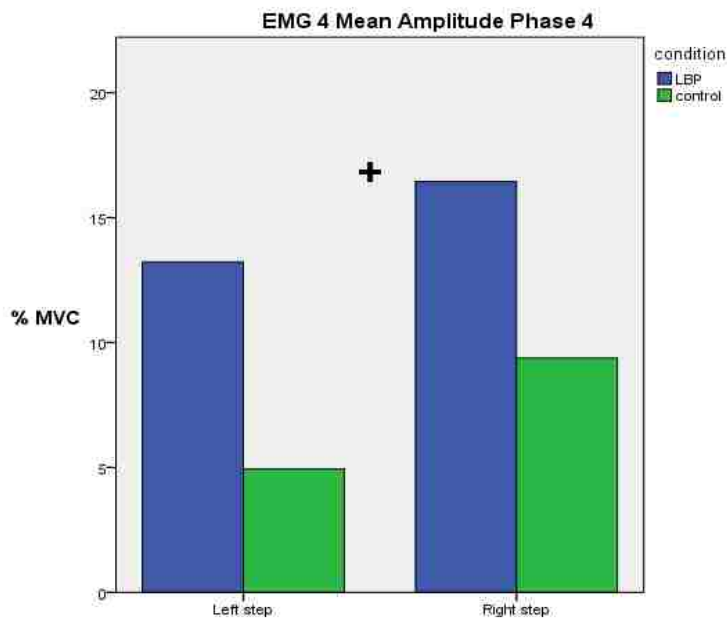


Figure 46. Left lumbar extensors has within group difference in phase 4 (= final single support phase) between left and right steps ( $p < .05$ ).

### Lower Extremity Muscle EMG Activation Phase 4

Repeated measure ANOVA demonstrated between group significance in EMG 5 ( $p=.041$ , power= .95) with higher activation levels in the LBP group in right steps. See table 20 and figure 47. Within group significance was found ( $p=.000$ , power= .99) with higher activation on right steps in both groups.

A repeated measure ANOVA demonstrated between group significance in EMG 6 ( $p=.016$ , power= .99) with higher activation levels in the LBP group in left and right steps. See table 20 and figure 48. Within group significance was also found ( $p= .000$ , power= 1.00) with higher activation on left steps in both groups.

Table 20

#### *Lower Extremity Muscle Activation Level Phase 4*

Phase 4 Group	EMG 5		EMG 6		EMG 7		EMG 8	
	%MVC +/- SD		%MVC +/- SD		%MVC +/- SD		%MVC +/- SD	
	Left	Right	Left	Right	left	Right	Left	Right
LBP	51.0	56.8*	39.5*	23.5*	13.5*	16.9*	16.1*	10.0*
	+/-20	+/-19	+/-20	+/-18	+/-8	+/-6	+/-5	+/-7
Controls	36.1*	40.0*	20.4	10.3	10.0	13.6	11.5	6.7
	+/-15	+/-14	+/-12	+/-4	+/-3	+/-4	+/-4	+/-3

*Note.*

\*EMG 5; between;  $p=.041$ , power= .95, within;  $p= .000$ , power= .99

\*EMG 6; between;  $p=.016$ , power= .99, within;  $p= .000$ , power=1.00

\*EMG 7; within;  $p= .002$ , power= .99

\*EMG 8; within;  $p= .000$ , power= 1.00

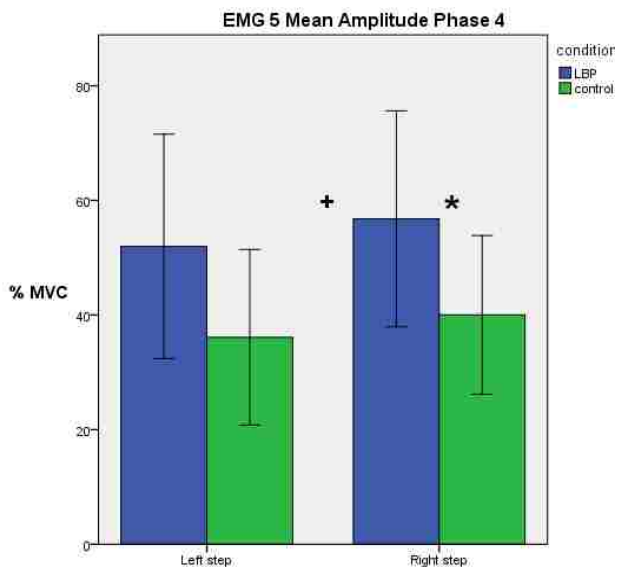


Figure 47. Right hip abductors have higher activation in right steps ( $p < .05$ ) and within group difference in left and right steps ( $p < .05$ ).

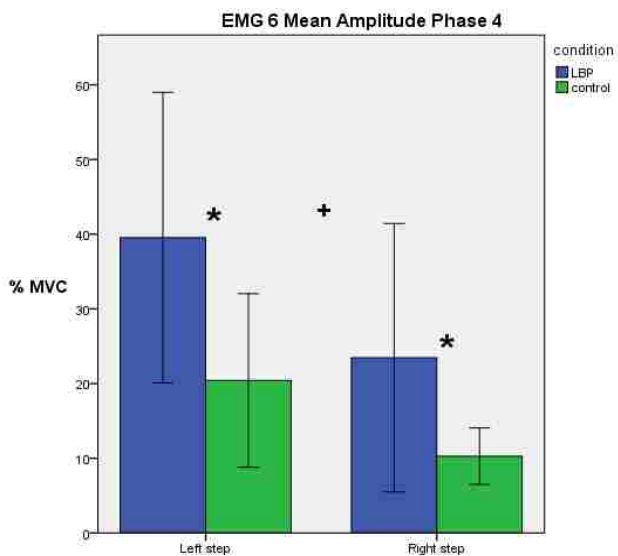
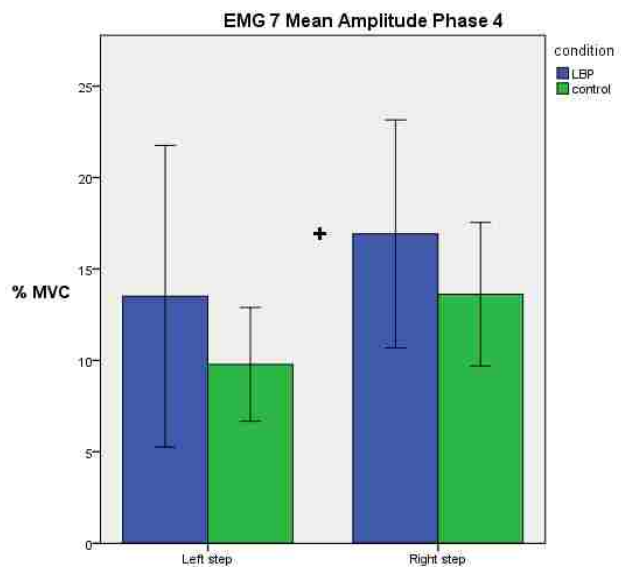


Figure 48. Left hip abductors have higher activation on left and right side ( $p < .05$ ) and within group difference left and right side ( $p < .05$ ).

A repeated measure ANOVA demonstrated within group difference of EMG 7 ( $p = .002$ , power = .99) with higher activation in right steps in both groups. See figure 49. EMG 8 also demonstrated within group difference ( $p = .000$ , power = 1.00) however, with higher activation in left steps. See figure 50.



*Figure 49.* Right calf has within group difference between left and right side ( $p < .05$ ).

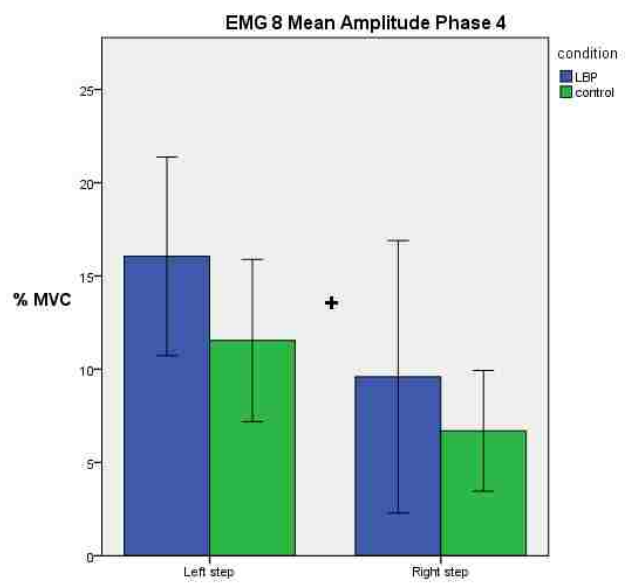
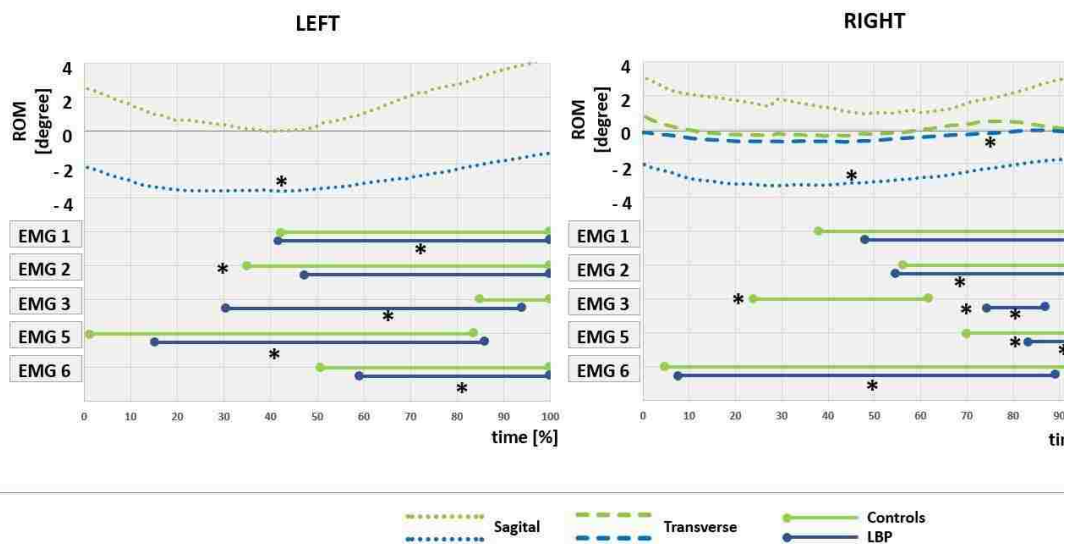


Figure 50. Left calf has within group difference between left and right steps ( $p < .05$ ).

## V. DISCUSSION

The results demonstrate that the LBP group move the trunk to a lesser extend primarily in the phases with single leg weight bearing in phases 2 & 4; See figure 51 and 53. In particular lumbar extension is less than the control group when weight bearing unilaterally. This lesser inclination to perform a curve reversal of the lumbar spine by moving pelvis forward to increase the lumbar lordosis could be linked to the increased activation of the abdominal muscles seen especially on left steps. The co-contraction of these two antagonistic muscles, lumbar extensors and the abdominals, indicate a guarding strategy possibly adopted based on previous experiences of painful movements of the spine when the LBP was acute and possibly much higher than at the time of the study when the subjects overall had low levels of pain. Further indication a potential reluctance to allow movement of the lumbar spine is the reduced left rotation in phase 2 in right steps. The mechanism for this reduced trunk rotation may be the higher amplitudes of right lumbar extensor (EMG 3) when eccentrically lowering the pelvis as trailing leg and pelvis is being lowered just before first weight acceptance.





*Figure 51.* Phase 2 EMG onsets/offsets and ROM. Only first EMG onsets/offsets displayed. EMG activation when significant between groups is indicated with a \* under the respective EMG onset line ( $p < .05$ ). Significant difference in onset time between groups is indicated with a \* to the left of the respective EMG onset line ( $p < .05$ ). Significant difference between groups in ROM is indicated with a \* at the respective plane of motion ( $p < .05$ ).

The results demonstrate that the LBP group overall activate their trunk and hip muscles to a higher degree than the control group for all trunk muscles tested as well as the hip abductors; See figure 51, 52 and 53.

Higher activation of left hip ABD (EMG 6) might be due to less inclination to bend left required for foot clearance (longer onset Right hip ABD- EMG 5- might assist in foot clearance). A higher activation of the hip abductor might lead to higher elevation of the leg for enhanced foot clearance which again would likely

result in a lesser demand for trunk mobility. In both phase 2 and 3 the hip abductors demonstrate higher activation levels in conjunction with higher activation of trunk muscles in particular on left step; This collaborates the findings of Nelson-Wong and Callaghan (2010) indicating co-contraction of trunk and hip abductors. The authors noted this was in subjects developing pain, not currently presenting LBP: This suggest a predisposition that aligns with the fact that in the current study's subjects were indeed having low levels of pain but have chronic and/or recurrent bouts of LBP.

Furthering the notion that the individuals with LBP move with more caution can be seen in the slower Z GRF rise at first weight acceptance (P3); See figure 52 (phase 3). Left hip abductor (EMG 6) higher eccentric activation levels might indicate attempt to lessen impact upon first weight acceptance at P3. On right steps the right hip abductor (EMG 5) presents delayed onset indication alteration of the anticipatory control in preparation for weigh acceptance and when it finally contracts it has a higher activation level than the control group suggesting a guarding mechanism. The delayed onset right hip abductor (EMG 5) & right lumbar extensor (EMG 3) coupled with higher activation of same may be part of a stabilizing strategy (co-contraction) on left step.

Delayed right lumbar extensor (EMG 3) onset on right, but similar on left indicate a different motor strategy in preparation for weight acceptance pending

side. Considering the late onset of left abdominals (EMG 2) coupled with higher activation right abdominals (EMG 1) on left steps and in conjunction with the findings discussed above showing more differences between the groups on left step it suggest a higher level of compromised motor control on left steps as a whole.

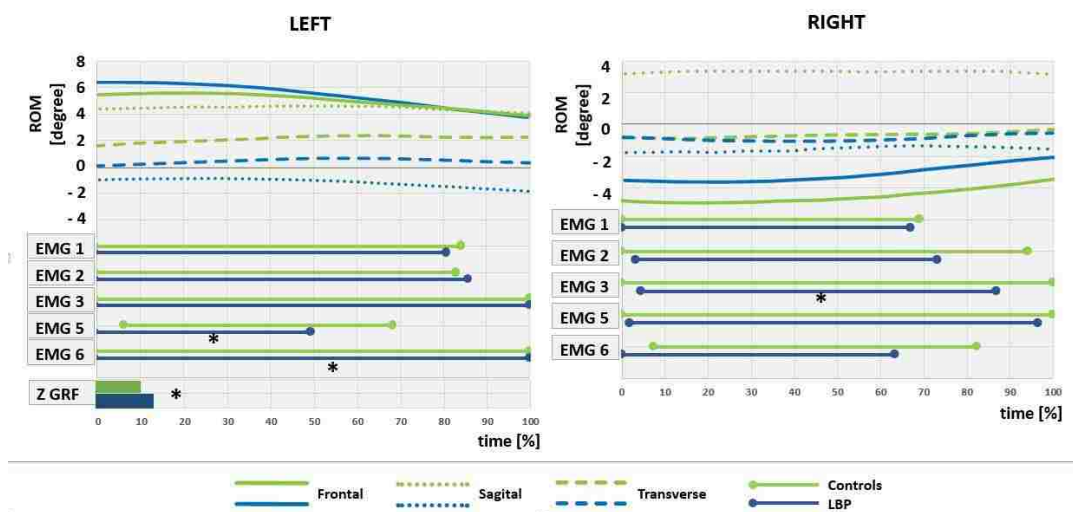
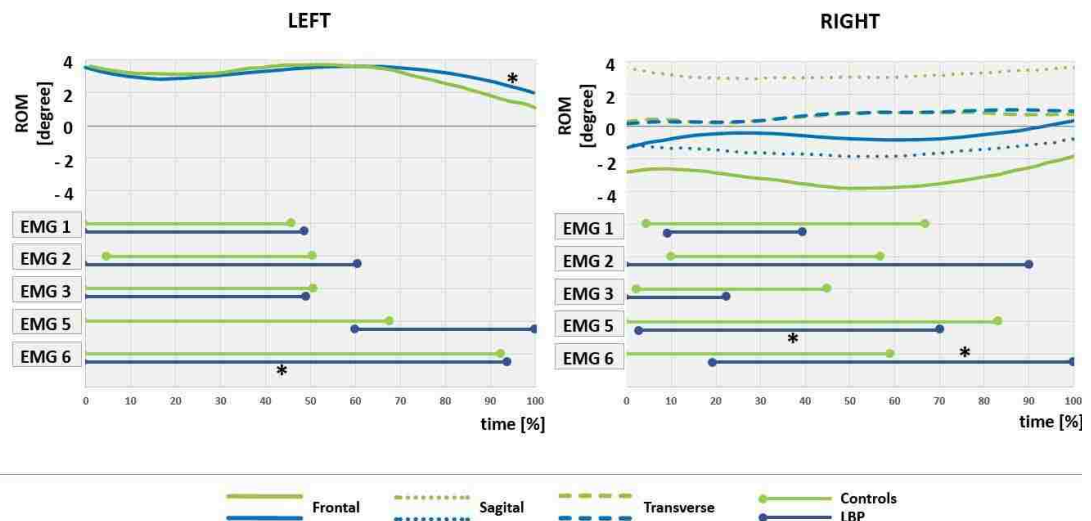


Figure 52. Phase 3 EMG onsets, ROM and GRF time to first peak (z-force). Only first EMG onsets/offsets displayed. EMG activation when significant between groups is indicated with a \* under the respective EMG onset line ( $p < .05$ ). Significant difference in onset time between groups is indicated with a \* to the left of the respective EMG onset line ( $p < .05$ ). GRF significance seen on left only ( $p < .05$ ).



*Figure 53.* Phase 4. EMG onsets and ROM. Only first EMG onsets/offsets displayed. EMG activation when significant between groups is indicated with a \* under the respective EMG onset line ( $p < .05$ ). Significant difference in onset time between groups is indicated with a \* to the left of the respective EMG onset line ( $p < .05$ ). Significant difference between groups in ROM is indicated with a \* at the respective plane of motion ( $p < .05$ ).

The calf muscles demonstrated no significance between the groups and only within group difference for both groups. The activation of the calf muscles follow the demand of the task as would be expected with higher activation levels on the leading leg, in particular in phase 3; double stance. This is possibly due to the high demand for stability on this weight bearing side as the weight bearing is in a transitional phase from eccentrically being loaded and the heel is descending after arriving on the lower platform and has to assist in weight bearing as the trailing leg descend. This collaborate the view of the calf muscles

assist in deceleration and stabilization (Benedetti, 2012) though no group difference were found in this study.

Fear avoidance has been contributed as a factor in decreased activity levels of individuals with LBP. This coupled with research finding of reduction of mobility (Lamoth, 2004, Selles, 2001) can explain the finding of a similar pattern in the current study. However if one considers the low levels of pain the current study's' subjects display of less than 27 mm on the VAS and less than 6 on the Oswestry disability questionnaire it would not appear that a fear based behavior is not present at the time of the study.

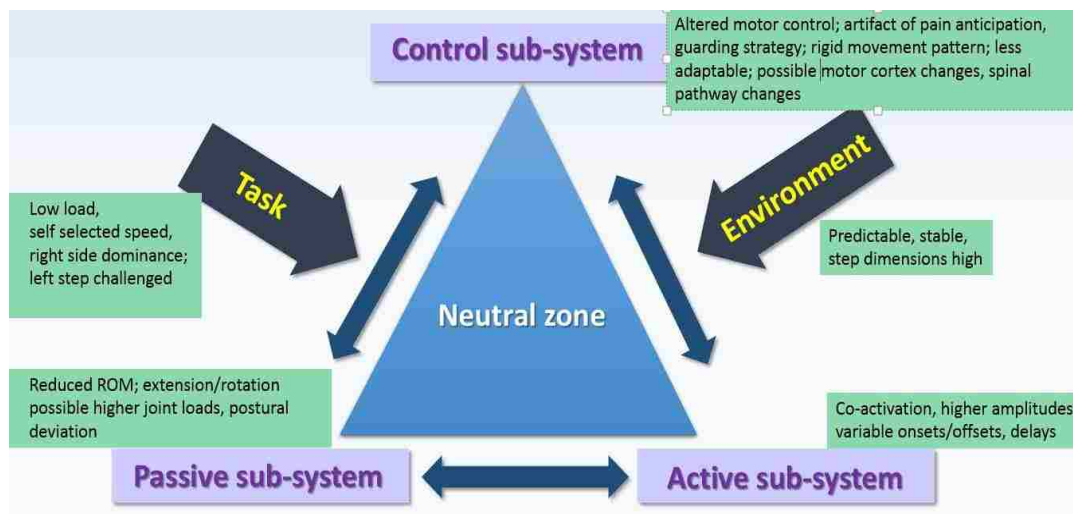
Changes in cortical representation as see in studies by Tsao et al. (2008) in indicate that pain occupies a larger part of the brain than on control subjects and invades areas of the motor cortex and cognitive changes are present long after an insult to the spine; It is plausible that in individuals with LBP have lost some cortical representation of areas previous dedicated to motor control to pain perception, processing and coping; That could again affect ability to execute effective motor strategies and could result in over firing and poor synchronization of trunk and lower extremity muscles.

Pathologic changes in lumbar segments can case impact on nerve innervation which could be a factor in the increased muscle activity found in the current study as a compensatory strategy for the lack of muscle mass and innervation. Muscle atrophy has been found in individuals with LBP (Beneck et

al., 2012, Cai & Kong, 2015, D'Hooge et al., 2012) and the current study's finding of increased muscle activity in lumbar spine extensors may play a role.

Side dominance of upper extremity and lower extremity has been related to balance with right handed and right-footed individuals demonstrating higher levels of stability in quiet stance on right side than on left side (Kinsalla-Shaw et al. 2013). This can be one factor explaining why subjects in this study demonstrate more affected performance during left stepping as the majority of the subjects were right footed. Furthermore, as the first second of unilateral weight bearing is the most dynamically challenging (Johnsson et al., 2005). So, the fact that the subjects with LBP were more challenged on the left side suggest that stepping with the non-dominant side presented a dynamic challenge.

In summary, relating to the dynamics systems model and Panjabi's model of the spinal stabilizing system it is found that subjects with LBP present changes of biodynamic parameters indicative of altered movement strategies likely an artifact of previous higher levels of LBP. See figure 54 below for a summary diagram of discussion points and relationships.



*Figure 54.* Current study's main discussion points in a dynamic systems model with Panjabi's model of spinal stabilizing system imbedded. Diagram by Kim M. Poulsen.

So, it follows that 9 of 19 sub-hypotheses were supported per the discussion above. See table 21 below for an overview.

Table 21

*Overview of Hypotheses support*

<b>Hypothesis</b>	<b>Status</b>
<b>H1: There will be a difference in ROM of the trunk in phases 2 &amp; 4 between subjects with and without LBP with respect to side (L/R).</b>	
H1a: There will be a difference in ROM of the trunk in phases 2 & 4 within subjects (with and without LBP) with respect to side (L/R).	<b>Unsupported</b>
H1b: There will be a difference in ROM of the trunk in phases 2 & 4 between subjects (with and without LBP) with respect to side (L/R).	<b>Supported</b>
H1c: There will be an interaction in ROM of the trunk in phases 2 & 4 between subjects (with and without LBP) and side (L/R).	<b>Supported</b>
<b>H2: There will be a difference in ROM of the trunk in the full step, phases 2 through 4 between subjects with and without LBP with respect to side (L/R).</b>	
H2a: There will be a difference in ROM of the trunk in the full step, phases 2 through 4 within subjects (with and without LBP) with respect to side (L/R)	<b>Unsupported</b>
H2b: There will be a difference in ROM of the trunk in the full step, phases 2 through 4 between subjects (with and without LBP) with respect to side (L/R)	<b>Unsupported</b>
H2c: There will be an interaction in ROM of the trunk in the full step, phases 2 through 4 between subjects (with and without LBP) with respect to side (L/R)	<b>Unsupported</b>
<b>H3: There will be a difference in postural muscle activity in phases 2 &amp; 4 between subjects with and without LBP with respect to side (L/R)</b>	
H3a: There will be a difference in postural muscle activity in phases 2 & 4 within subjects (with and without LBP) with respect to side (L/R)	<b>Supported</b>
H3b: There will be a difference in postural muscle activity in phases 2 & 4 between subjects (with and without LBP) with respect to side (L/R)	<b>Supported</b>
H3c: There will be an interaction in postural muscle activity in phases 2 & 4 between subjects (with and without LBP) with respect to side (L/R)	<b>Supported</b>



<b>H4: There will be a difference in postural muscle activity in the full step, phases 2 through 4 between subjects with and without LBP with respect to side (L/R)</b>	
H4a: There will be a difference in postural muscle activity in the full step, phases 2 through 4 within subjects (with and without LBP) with respect to side (L/R)	<b>Unsupported</b>
H4b: There will be a difference in postural muscle activity in the full step, phases 2 through 4 between subjects (with and without LBP) with respect to side (L/R)	<b>Unsupported</b>
H4c: There will be an interaction in postural muscle activity in the full step, phases 2 through 4 between subjects (with and without LBP) with respect to side (L/R)	<b>Unsupported</b>
<b>H5: There will be a difference in postural muscle onsets at first weight acceptance (P3) between subjects with and without LBP with respect to side (L/R)</b>	
H5a: There will be a difference in postural muscle onsets at first weight acceptance (P3) within subjects (with and without LBP) with respect to side (L/R)	<b>Supported</b>
H5b: There will be a difference in postural muscle onsets at first weight acceptance (P3) between subjects (with and without LBP) with respect to side (L/R)	<b>Unsupported</b>
H5c: There will be an interaction in postural muscle onsets at first weight acceptance (P3) between subjects (with and without LBP) with respect to side (L/R)	<b>Supported</b>
<b>H6: There will be a difference in Ground Reaction Force between subjects with and without LBP at first weight acceptance (P3)</b>	
H6a: There will be a difference in Ground Reaction Force within subjects (with and without LBP) at first weight acceptance (P3)	<b>Unsupported</b>
H6b: There will be a difference in Ground Reaction Force between subjects (with and without LBP) at first weight acceptance (P3)	<b>Supported</b>
H6c: There will be an interaction in Ground Reaction Force between subjects (with and without LBP) at first weight acceptance (P3)	<b>Unsupported</b>
<b>H7: sEMG will be reliable</b>	<b>Supported</b>

### Limitations

A limitation to this study is the use of a rigid model when creating the 3D model used for data analysis. Albeit a standard procedure in kinematic studies the model considers only one joint for excursion that is derived from the movement data: In this case the lumbar spine is essentially viewed as one joint with an axis between the trunk and the pelvis. This, therefore will not be able to detect any segmental movements of the lumbar spine in itself and will not be able to recognize any movement contribution from the thoracic spine either. Different modeling could be considered though it may necessitate more markers on the subject.

Care was taken to limit the heart ECG contribution to the EMG that in nature registers any electrical signal in its vicinity. This was primarily accomplished by applying a filter per Winter (1990). Therefore a higher risk of contamination of especially the trunk EMG of left side abdominals and lumbar extensors existed. During the visual inspection of the EMG data some ECG artifact were noted and trials with noticeable contamination was omitted in the data analysis.

The pain location nor the spinal level of pain of the subjects were not tracked objectively. However subject made an indication on a body diagram as to the location of pain and center low back were predominantly reported though

any subtleties cannot not be drawn from that. It is therefore possible that if a certain side of the body or certain level of the spine had been more involved it could skew the results in a certain direction.

The clinical instability tests employed in conjunction with the self-report indicated lumbar instability were present in the subjects in the LBP group. This classification is based on a non-blinded clinical test and subjective testimony and not diagnostic imaging that is the gold standard for determining structural instability. This study does not claim to detect structural instability in the subjects with LBP however a clinical presentation exist.

The study did not control for vision or gaze stabilization and no instruction were given to the subject as to where to look during the step tasks. It is possible that if a subject is looking around the lab while stepping that that could affect the recruitment pattern and potentially alter the performance of the task.

The study did not control for footwear: The subjects were using their own regular shoes whether they were sneakers and regular walking shoes. Differences in heel height of footwear could have affected the performance as higher heels may incline a subject to select a different foot-ankle position as they step down as opposed to a lower heel might provide less cushioning and the subject may then choose to slow the descend in order to lessen the impact on the lower platform.

Anthropometric measures as leg length was not taken on subjects. It is possible that some subject might have a difference between the length of their lower extremities that could have influenced their performance when comparing performance between stepping with the left or right leg first.

## VI. CONCLUSIONS

This study demonstrated that in subjects with low back pain, chronic or recurrent, and a clinical classification of lumbar instability that leading with left leg presented more dynamic challenges than leading with right leg compared to a control group.

The subjects with low back pain demonstrated co-activation of hip abductors & and lumbar extensors when the control group did not.

The subjects with low back pain were less inclined to move the trunk into extension or disassociate in rotations and left side-bend.

In all, the subjects appear to have adopted of a high load motor strategy for a low load step task.

### Clinical Implications

For individuals with low levels of pain and low levels of disability with a history of chronic or recurrent LBP classified with lumbar spine instability on clinical tests the following should be considered:

As this study demonstrate that left stepping pose more challenge than right stepping unilateral movement activities including left leg weight bearing

activities should be examined by the clinician to determine if there are asymmetries and based on results addressed in the plan of care.

The evidence of reduced disassociation of pelvis and trunk found in this study suggest practicing movements that focus on this disassociation and allow the trunk to rotate in relation to the pelvis might be beneficial.

Reduced trunk extension demonstrated in this study's subjects also suggest practice of extension movements might be beneficial.

The overall reduction of ROM displayed by the subjects with LBP indicate and shift toward stability. As a subject is no longer in an acute phase of LBP where stability of the spine may be preferred in later phases introduction of controlled mobility for low load tasks should be considered as it potentially could make movements more effective and reduce the spinal load which. However, in high load activities it is preferred to limit trunk ROM in the presence of lumbar spine instability, as during high load tasks as lifting that is when risk is higher for tissue damage. This is not the case for low load tasks as walking and stepping thus is should be considered to shift the emphasis from stability to controlled mobility of the trunk during such tasks.

Eccentric muscle activity of hip abductors should be considered as these muscles play a significant role in the deceleration of the body during step and stair descending. As both hip abductors had various level of alteration in the subjects with LBP it should be considered to include activities that include

eccentric strength and control of hip abductors. One activity example could be in the form of graded step descend.

The above suggestions should not be viewed in isolation and following evidence based practice guidelines the clinician should perform a thorough examination of the patient about to receive treatment for LBP incorporating all elements of EBP and assess the response and outcomes continuously in collaboration with the patient and health care providers involved.

### Further research

Further research in to the biodynamic parameters of subjects performing a step task should consider including continued walking versus come to a standstill as is likely that the movement strategy will be different. Furthermore, continued walking after stepping down simulate real life functional mobility to a high degree. When designing the step task the speed of task should be considered. The current study utilized a self-selected speed and it is possible that adding a higher speed, simulation being in a hurry, may illuminate additional differences between groups.

As intra-abdominal pressure has shown to have some effect on lumbar spine stability including various levels of involvement of the respiratory muscles

might illuminate its role in functional tasks as stepping and walking. Diaphragmatic breathing and performing a Valsalva maneuver as variables is recommended.

Since the cognitive load in a subject with some forms of functional alteration do play a role in even low load tasks including dual tasks in further research is recommended as well: It is a common everyday event to both be walking and talking, being on the phone and stepping carrying a shopping bag to name a few. In the spirit of designing research that simulate everyday function as close as possible without sacrificing reliability a final suggestion is to consider surface variability as step tasks in real life often included uneven and slippery surfaces.



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## APPENDIX A

## IRB Approval letter



June 17, 2014

Kim Poulsen, PT, DPT  
McQuaid Hall  
Seton Hall University  
400 South Orange Avenue  
South Orange, NJ 07079

Dear Doctor Poulsen:

The protocol, informed consent, Subject Information and Activity Log, Letter of Solicitation, Recruitment Flyer and Questionnaire you presented were approved by the Institutional Review Board on June 17, 2014, for a one-year period through June 17, 2015:

Biodynamic Parameters during a Step Down Task in Subjects with Chronic or Recurrent Low back Pain Classified with Lumbar Instability (Protocol, Informed Consent, Subject Information and Activity Log, Letter of Solicitation, Recruitment Flyer, Questionnaire) – Low Risk – #18/14

If any changes/modifications are made to this protocol, the IRB must be notified immediately. If any changes/modifications are made, a new and complete application must be submitted for approval.

All serious adverse effects or deaths must be reported immediately to the IRB. According to the terms of the one-year approval, you must report back to the IRB annually on the progress of the investigation. In approximately ten months, you must request an extension of this approval for an additional twelve-month period, if needed, by writing to the Chairman of the IRB. A brief report must be included with the request for an extension of approval, including the number of patients involved, age, sex, major diagnoses and a brief summary of results. Upon completion of every study, a brief summary of results must be sent to the IRB.

For studies involving drugs for inpatient use, the drug must be deposited with the pharmacy for dispensing. In addition, two copies of the consent form must be signed by the patient. One copy with be kept on the patient's chart, the other filed in the pharmacy.

Sincerely,

Constantinos A. Costeas, M.D.  
Chairman  
Institutional Review Board

mf

cc: Mary Ruzicka, PhD, Seton Hall, IRB  
Dean Brian Shulman, Seton Hall

## APPENDIX B

## Recruitment Flyer

Individuals with and  
without **Low Back Pain**  
Needed to help  
**Scientific Study**



Individuals needed who:

- Are **18 years or older**
- Have **Chronic or Recurrent**  
Low Back Pain

-or

- Are **Pain Free**

Procedures:

- Preliminary eligibility to participate will be determined during an initial phone screening
- A **\$10<sup>00</sup> Gift certificate** will be given for participating in a brief physical exam to further determine eligibility
- Another **\$10<sup>00</sup> Gift Certificate** will be given if deemed eligible and included in the study:
  - This one-time session includes the performance of step downs from a standard step height.
- Muscle activity and movement will be measured
- The entire session is approximately one hour long and takes place in a Movement Science Lab on the **Seton Hall University** campus in South Orange, NJ

If interested, please contact Dr. Kim Poulsen PT, DPT at  
[kim.poulsen@shu.edu](mailto:kim.poulsen@shu.edu) or at (201) [REDACTED]

APPROVED  
mf 12/16/14

## APPENDIX C

### Phone Script

-Thank you for your interest in the study. This conversation will take about 10 minutes. Shall we continue? If Yes: Proceed. If No: Plan another time for the conversation.

-Let me tell you about the study:

#### **Researcher's affiliation**

-Dr. Poulsen is the Director of Clinical Education in the Doctor of Physical Therapy Program in School of Health and Medical Sciences at Seton Hall University. The study is part of Dr. Poulsen's PhD project in the Graduate Programs in Health Sciences in the School of Health and Medical Sciences at Seton Hall University

#### **Duration**

-The amount of time you will spend in the laboratory is approximately 1 hour.

#### **Purpose**

-The purpose of the study is to test reliability of the methodology and for differences between control subjects and subjects with LBP.

#### **Voluntary participation**

-Your participation is purely voluntary. You are free to withdraw from this study at any time without penalty.

#### **Anonymity**

-Your identity will be protected by coding the data and information sheets. When you arrive for your session you will be assigned a subject number after which your identity will no longer be associated with your participation data.

#### **Confidentiality**

-All your information will be confidential and kept in a locked cabinet in Dr. Poulsen's office and destroyed after 3 years.

-Are you still interested? If; Yes: Proceed If; No: Thank you. You are excused from the study.

**Procedures**

-Let me inform you what the study will entail if you are included in the study:

**Testing session**

- You will be awarded a \$10 gift certificate for attending the screening session.
- You will bring a completed questionnaire about pain and the signed consent form.
- You will arrive dressed in shorts and a t-shirt or can change behind a curtain.
- Your height and weight will be measured to calculate a body/mass index.
- You will indicate your pain level and pain location (if present).

You will have your lumbar spine examined by receiving manual pressure on the lumbar spine and have you legs lifted by the investigator while you are on your stomach on an examination table. These procedures may induce transient discomfort. The result of this procedure will determine if you can be included in the study to take place immediately after this screening.

If determined you can be included in the study based on the BMI index and the lumbar spine exam you will receive another \$10 gift certificate.

-You will have skin sensors attached to your stomach, low back and hips; a total of 8 locations. The sensors are recording devices that detect electrical activity in your muscles and send a signal to a computer for analysis. They do not transfer any electricity to your body. If you have a lot of hair at a location for skin sensor placement, hair will be removed with a single-use dry-razor.

-Reflective markers will be placed on your leg, pelvis and trunk. This is for a camera system to detect your movements. The cameras will only detect light reflections from the markers.

-Next you will be asked to step down from a step 9.5 inches high 13 times.

- You will be asked to perform a series of movements to test muscle strength. Each test will require two repetitions with a strong hold of the muscle.

-Finally the skin sensors and reflective markers will be removed and the session is completed.

-Do you have any questions?

-Are you still interested? If: Yes: Proceed. If: NO: Thank you. You are excused from the study.

### **Inclusion/Exclusion criteria**

-Let me ask you some questions to see if you meet the inclusion criteria or if any of the exclusion criteria are present. Please understand that in order to ensure standardization there are certain features that might exclude you from participating. This is purely because of the study design requirements.

If subject has self-identified as having low back pain:

On a pain scale 0-10, 10 indicating the worst possible pain and zero no pain, what is your current average back pain?

If >2/10 proceed. If 2/10 or less: Thank you. You are excused from the study.

-What is your age? \_\_\_\_\_ Years.

If 18 years or older: Proceed. If not in range: Thank you. You are excused from the study.

-How tall are you? \_\_\_\_\_ How much do you weigh? \_\_\_\_\_(.....lbs)\_\_\_\_\_

Researcher will calculate BMI from information provided. If BMI < 30: Proceed. If 30 or higher: Thank you. You are excused from the study.

-Are you independent when walking, climbing stairs and negotiating curbs?

If Yes: Proceed. If No: Thank you. You are excused from the study.

If subject has self-identified as a control subject (no LBP) skip this question:

-Do you currently have back pain that has lasted more than 3 month, or have you experienced back pain in the past year for more than three months more than once?

If yes: Proceed. If No: Thank you. You are excused from the study.

If subject has self-identified as a control subject (no LBP) skip this question:

-Do you ever have a feeling of back "giving way" or "giving out", a need to pop or crack the back, painful locking of back, pain during transitions as sit-to-stand, increased pain returning upright from forward bending, pain with trivial movements, difficulty with unsupported sitting, worse with sustained positions, shorter intervals between bouts of pain, relief with back brace or corset, frequent muscle spasms?

If Yes to one or more of the symptoms/experiences: Proceed.

If No: Thank you. You are excused from the study.



-Have you ever had surgery to your low back?

If No: Proceed. If Yes: Thank you. You are excused from the study.

-Are you currently pregnant?

If: No: Proceed. If: Yes: Thank you. You are excused from the study.

If subject has self-identified as having low back pain:

-I will email you a survey regarding your low back pain. Please complete this survey and email it back to me. I will check it and based on clinical criteria the result will include or exclude you from the study. I will notify you.

-Thank you so much. You are preliminary included in the study. We will now find a convenient time for your testing session, and I will send you the consent form to review and the questionnaire to complete.

## APPENDIX D

## Consent Form

Subject name: \_\_\_\_\_ Date: \_\_\_\_\_

**Name of study**

Biodynamic parameters during a step down task in subjects with chronic or recurrent low back pain classified with lumbar instability

**Researcher's affiliation**

The investigator, Dr. Poulsen is the Director of Clinical Education in the Doctor of Physical Therapy Program in School of Health and Medical Sciences at Seton Hall University. The study is part of Dr. Poulsen's PhD project in the Graduate Programs in Health Sciences in the School of Health and Medical Sciences at Seton Hall University.

**Purpose**

The purpose of the study is to investigate the difference between control subjects and subjects with low back pain during a step down from a single step.

**Duration**

The subject will spend approximately 1 hour in the laboratory.

**Procedures**

The procedures include the following:

Upon arrival the subject will be awarded a \$10 gift certificate.

The subject will arrive dressed in shorts and a t-shirt or can change behind a curtain.

Subject height and weight will be measured to calculate a body/mass index. A standard wall mounted tape and electronic scale will be used.

## **Subjects**

Subjects **with low back pain** will be asked to indicate their pain location on a body diagram and their level of pain on a scale on a piece of paper.

Subjects **with low back pain** or a history of low back pain will be asked to fill out the Modified Oswestry Pain and Disability Questionnaire and bring to the testing session or email in advance to researcher. The questionnaire examines how the low back pain affects daily activities. Completion of the questionnaire will take about 10 minutes.

All subjects will receive the **two** following tests:

### **1: Prone Instability test**

Standing in front of an examination table, at the foot-end, the subject will lean forward to rest the entire trunk on the table while the feet remain on the floor. The subject will grasp the side of the table for comfort. Next the investigator will apply pressure to the low back. This pressure may cause transient discomfort. The examiner will stop the pressure if the subject reports discomfort. If discomfort is not present the test is considered completed. Should the subject report discomfort the examiner will stop the pressure, ask the subject to lift the feet slightly off the floor when pressure will be re-applied: This pressure may also induce transient discomfort. The procedure will take less than one minute.

### **2: Passive Lumbar Extension Test**

With the subject resting face down on the examination table, entire body supported on the table, the examiner will hold the feet of the subject and elevate the legs to approximately 14 inches above the table. This may cause transient discomfort. Examiner will stop the elevation of the legs at any point before the 14 inches is reached should the subject report discomfort. This procedure will take less than half a minute.

If the examiner determines the subject cannot be included in the study based on the results of the BMI index and tests (1) and (2) the session will end.

If the examiner determines the subject can be included in the study based on the results of the BMI index and tests (1) and (2) the subject will be awarded another \$10 gift certificate. In that case the session continues:

Next, skin sensors will be attached to the subject for a total of 8 sensors: Stomach, low back and hips. The sensors are recording devices that detect electrical activity from the muscles and send a signal to a computer for analysis. The sensors do not transfer any electricity to the subject. If the subject has a lot of hair at a location for skin sensor placement, hair will be removed with a single-use dry-razor.

Next, reflective markers will be placed on the subject's legs, pelvis and trunk. This is for the camera system to detect movements. The cameras will only detect light reflections from the markers.

Next the subject will be asked to stand still on a platform 9.5 inches high for a couple of seconds for a baseline capture of the reflective markers.

Next the subject is asked to step down from the platform 3 times for practice.

Next, the subject will be asked to step down from the platform 5 times on both right and left side; 10 total.

Next, the subject will be asked to perform 3 different muscle strength tests with a strong hold of the muscle for 4 seconds. The tests are designed in a manner not to cause pain or discomfort:

Subject will lie on the stomach on a treatment table and lift the upper body from the table without using hands and hold for 4 seconds. This will be repeated twice.

Next, the subject will be asked to turn to his or her back with arms crossed at the chest and then lift the trunk high enough to clear the lower part of both shoulder blades off the surface of the table and hold for 4 seconds. This will be repeated twice.

Next the subject will turn to one side and lift the upper leg against a strap and hold for 4 seconds. This will be repeated twice.

Next the subject will turn to the other side and repeat the same test.

Lastly, the subject will stand on one leg, while holding on to a table for balance and lift heel off the floor and hold for 4 seconds. This will be performed twice on both legs.

Finally the skin sensors and reflective markers will be removed; and the session is completed.

### **Voluntary participation**

Participation is purely voluntary. Subject is free to withdraw from the study at any time without penalty.

### **Anonymity**

The identity of the subject will be protected by coding the data and information sheets. When the subject arrive for the testing session he or she will be assigned a subject number after which the identity of the subject will no longer be associated with the information or data collected. The subject will never be able to be linked to the data collected.

### **Confidentiality**

All data and information will be confidential and kept in a locked cabinet in Dr. Poulsen' s office and destroyed after 3 years. Data collected on the subject will only be stored on an external memory device and likewise kept in a locked cabinet in Dr. Poulsen' s office and destroyed after 3 years. Only Dr. Poulsen will have access to the records on the subject.

### **Risk and Discomforts**

The risks associated with this study are minimal and involve the potential for mild soreness and transient discomfort. Subject is advised that if any of the activities is uncomfortable they can stop at any time. No aggravation of any existing low back pain is anticipated. Nevertheless, subjects will be advised to contact Dr. Poulsen should they experience any pain or discomfort following the testing session for referral to appropriate care.

### **Potential benefits**

There is no direct benefit to the subject in this study. By participating in this study the subject will help provide information that may assist in designing rehabilitation for individuals with low back pain.

**Compensation for Participation:**

\$10 gift certificate for attending screening session and another \$10 gift certificate if included in the study.

**Alternative procedures:** None.

**Contact Information:**

The subject has a right to get answers to any questions or concerns regarding the study:

The principal researcher, Dr. Kim Poulsen, should be contacted for answers to pertinent questions about the study. He may be reached at McQuaid Hall, 400 South Orange Avenue, South Orange, NJ 07079, or by phone at (973) 275-2963.

The research advisor of Dr. Poulsen, Dr. Lee Cabell EdD., can be contacted for any questions or concerns at Alfieri Hall, 400 South Orange Avenue, South Orange, NJ, 07079, or by phone at (973) 275 2049.

**Statement:**

A copy of the consent form will be given for the subject's records. Consent to participate is indicated by signing and submitting the informed consent to the investigator.

The subject does not waive or give up any legal rights by signing this consent form or by participating in this research project.

*The Department of Health and Human Services requires that you be advised as to the availability of medical treatment if a physical injury should result from research procedures. No special medical arrangements have been made regarding your participation in this project. If you are a registered student at SHU, you are eligible to receive medical treatment at the University Health Service. If you are not a registered student at the University, immediate medical treatment is available at usual and customary fees at the local community hospital.*

*In the event you believe that you have suffered any injury as a result of the participation in the research program, please contact the Chairperson of the IRB (phone number 973 313-6314) who will review the matter with you and identify any other resources that may be available to you.*

Name (please print)

Date

Signature

## APPENDIX E

## EMG script.

Dr. Lee Cabell, 2014. Seton Hall University, South Orange, NJ.

```
** __Add_a_Comment__ **
```

```
! /COMMENT= Compute the baseline value for each emg signal.
```

```
;
```

```
Select_Active_File
```

```
/FILE_NAME=ALL_FILES
```

```
! /QUERY=
```

```
;
```

```
Event_Explicit
```

```
/EVENT_NAME=BASELINE_START
```

```
/FRAME=1
```

```
! /TIME=
```

```
;
```

```
Event_Explicit
```

```
/EVENT_NAME=BASELINE_END_10
```

```
/FRAME=10
```

```
! /TIME=
```

```
;
```

```
Select_Active_File
```

```
/FILE_NAME=MVC
```

```
! /QUERY=
```

```
;
```

```
Event_Explicit
```

```

! The peak is calculated as the average +/- 1 frame from the maximum
!     If the peak occurs at the first or last frame, the peak cannot be calculated,
!     So only look for the max from the second to second to last frame
/EVENT_NAME=MAX_RANGE
/FRAME=2
!/TIME=
;
Event_Explicit
! The peak is calculated as the average +/- 1 frame from the maximum
!     If the peak occurs at the first or last frame, the peak cannot be calculated,
!     So only look for the max from the second to to the end of the trial (excluding the last
second of the trial)
/EVENT_NAME=MAX_RANGE
!/FRAME=
/TIME=EOF-1
;
** __Add_a_Comment__ **
!/COMMENT= Rectify and Lowpass filter the emg signals.
;
Select_Active_File
/FILE_NAME=ALL_FILES
!/QUERY=
;
Rectify
! Rectify raw analog signal
/SIGNAL_TYPES=ANALOG+ANALOG+ANALOG+ANALOG+ANALOG+ANALOG+ANALOG+ANALO
G

```



```

/SIGNAL_FOLDER=ORIGINAL+ORIGINAL+ORIGINAL+ORIGINAL+ORIGINAL+ORIGINAL+ORIGINAL+ORIGINAL+ORIGINAL
/SIGNAL_NAMES=EMG_1+EMG_2+EMG_3+EMG_4+EMG_5+EMG_6+EMG_7+EMG_8
!/RESULT_TYPES=
/RESULT_FOLDER=RECTIFY
/RESULT_NAMES=+++++++
!/RESULT_SUFFIX=
;
Lowpass_Filter
! Lowpass rectified analog signal
/SIGNAL_TYPES=ANALOG
!/SIGNAL_NAMES=
/SIGNAL_FOLDER=RECTIFY
!/RESULT_SUFFIX=
/RESULT_FOLDER=REC_LP
!/FILTER_CLASS=BUTTERWORTH
/FREQUENCY_CUTOFF=3.14
/NUM_REFLECTED=0
/TOTAL_BUFFER_SIZE=100
!/NUM_BIDIRECTIONAL_PASSES=1
;
** __Add_a_Comment__ **
!/COMMENT= Compute MVC for each MVC file.
;
For_Each
! For each EMG signal (emg channels 1 through 8)
/Iteration_Parameter_Name=INDEX

```

```
/Items= 1+2+3+4+5+6+7+8
;
  Select_Active_File
  ! Select EMG signal
  /File_Name=*mvc&::INDEX
;

  Event_Global_Maximum
  ! Create an event at the peak for current EMG channel
  !     Peak is calculated from the lowpass rectified signal
  /RESULT_EVENT_NAME=PEAK_MVC&::INDEX
  /SIGNAL_TYPES=ANALOG
  /SIGNAL_NAMES=EMG_&::INDEX
  /SIGNAL_FOLDER=REC_LP
  /SIGNAL_COMPONENTS=X
  ! /FRAME_OFFSET=0
  ! /TIME_OFFSET=
  /EVENT_SEQUENCE=MAX_RANGE+MAX_RANGE
  ! /EXCLUDE_EVENTS=
  ! /EVENT_SEQUENCE_INSTANCE=0
  ! /EVENT_SUBSEQUENCE=
  ! /SUBSEQUENCE_EXCLUDE_EVENTS=
  ! /EVENT_SUBSEQUENCE_INSTANCE=0
  ! /EVENT_INSTANCE=0
  ! /SELECT_X=
  ! /SELECT_Y=
```

```
!/SELECT_Z=  
!/SELECT_RESIDUAL=  
!/START_AT_EVENT=  
!/END_AT_EVENT=  
;  
Event_Copy  
! Create event range around peak  
/EVENT_NAME=PEAK_MVC&::INDEX  
/NEW_EVENT_NAME=MAX_MINUS_1  
!/EVENT_INSTANCE=0  
!/RANGE_INSTANCE=0  
!/EVENT_SEQUENCE=  
!/EXCLUDE_EVENTS=  
!/START_AT_EVENT=  
!/END_AT_EVENT=  
/FRAME_OFFSET=-1  
!/TIME_OFFSET=  
!/PERCENT_OFFSET=  
;  
Event_Copy  
! Create event range around peak  
/EVENT_NAME=PEAK_MVC&::INDEX  
/NEW_EVENT_NAME=MAX_PLUS_1  
!/EVENT_INSTANCE=0  
!/RANGE_INSTANCE=0  
!/EVENT_SEQUENCE=
```

```

!/EXCLUDE_EVENTS=
!/START_AT_EVENT=
!/END_AT_EVENT=
/FRAME_OFFSET=1
!/TIME_OFFSET=
!/PERCENT_OFFSET=
;
Metric_Mean
! Create mean +/- 1 frame from peak EMG
/RESULT_METRIC_NAME=MEAN_MVC&::INDEX
!/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=FALSE
/RESULT_METRIC_FOLDER=MVC
/SIGNAL_TYPES=ANALOG
/SIGNAL_NAMES=EMG_&::INDEX
/SIGNAL_FOLDER=REC_LP
!/SIGNAL_COMPONENTS=ALL_COMPONENTS
!/COMPONENT_SEQUENCE=
/EVENT_SEQUENCE=MAX_MINUS_1+MAX_PLUS_1
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FALSE
!/APPEND_TO_EXISTING_VALUES=FALSE
;
Evaluate_Expression
! Store average peak in the global workspace
!     This allows the metric to be used later in other trials
/EXPRESSION=METRIC::MVC::MEAN_MVC&::INDEX

```

```

        /RESULT_NAME=GLOBAL::MEAN_MVC&::INDEX
        /RESULT_TYPE=METRIC
        /RESULT_FOLDER=MVC
    ;
End_For_Each
/ITERATION_PARAMETER_NAME=INDEX
;
** __Add_a_Comment__ **
! /COMMENT= Normalize emg signals to MVC.
;
Select_Active_File
! Set all files as active
/FILE_NAME=ALL_FILES
! /QUERY=
;
For_Each
! For each EMG channel
/ITERATION_PARAMETER_NAME=NORM
/ITEMS=1+2+3+4+5+6+7+8
;
    Evaluate_Expression
    ! Divide the low pass rectified signal by the peak MVC
    /EXPRESSION=ANALOG::REC_LP::EMG_&::NORM&/GLOBAL::METRIC::MVC::MEAN_
MVC&::NORM
    /RESULT_NAME=EMG_&::NORM
    /RESULT_TYPE=ANALOG
    /RESULT_FOLDER=NORMALIZED

```

```
        ;
End_For_Each
/ITERATION_PARAMETER_NAME=NORM
;
** __Add_a_Comment__ **
! /COMMENT= Compute Median, Standard Deviation and Maximum values for each emg
signal.
;
Select_Active_File
! Set all files as active
/FILE_NAME=ALL_FILES
! /QUERY=
;
Metric_Mean
! Calculate the mean of the normalized EMG signal
!     Mean is calculated from the first 10 frames of data
/RESULT_METRIC_FOLDER=EMG
/RESULT_METRIC_NAME=_BASELINE_MEAN
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
/SIGNAL_TYPES=ANALOG
/SIGNAL_FOLDER=NORMALIZED
! /SIGNAL_NAMES=
! /SIGNAL_COMPONENTS=ALL_COMPONENTS
! /COMPONENT_SEQUENCE=
/EVENT_SEQUENCE=BASELINE_START+BASELINE_END_10
/EXCLUDE_EVENTS=
! /SEQUENCE_PERCENT_START=0
```

```
! /SEQUENCE_PERCENT_END=100
/GENERATE_MEAN_AND_STDDEV=FALSE
! /APPEND_TO_EXISTING_VALUES=FALSE
;
Metric_StdDev
! Calculate the standard deviation of the normalized EMG signal
!     Standard deviation is calculated from the first 10 frames of data
/RESULT_METRIC_NAME=_BASELINE_STDDEV
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
/RESULT_METRIC_FOLDER=EMG
/SIGNAL_TYPES=ANALOG
! /SIGNAL_NAMES=
/SIGNAL_FOLDER=NORMALIZED
! /SIGNAL_COMPONENTS=ALL_COMPONENTS
! /COMPONENT_SEQUENCE=
/EVENT_SEQUENCE=BASELINE_START+BASELINE_END_10
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FALSE
! /APPEND_TO_EXISTING_VALUES=FALSE
;

Metric_Maximum
! Calculate the maximum of the normalized EMG signal
/RESULT_METRIC_NAME=_MAX
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
/RESULT_METRIC_FOLDER=EMG
```

```

/SIGNAL_TYPES=ANALOG
!/SIGNAL_NAMES=
/SIGNAL_FOLDER=NORMALIZED
!/SIGNAL_COMPONENTS=ALL_COMPONENTS
!/COMPONENT_SEQUENCE=
/EVENT_SEQUENCE=
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FALSE
!/APPEND_TO_EXISTING_VALUES=FALSE
!/CREATE_GLOBAL_MAXIMUM=FALSE
;
** __Add_a_Comment__ **
!/COMMENT= Compute Onset and Offset events based on mean + 3 StdDev Threshold.
;
Select_Active_File
! Set the left and right tagged trials as active
/FILE_NAME=ALL_FILES
/QUERY=LEFT+RIGHT
;
Set_Pipeline_Parameter_From_Expression
/PARAMETER_NAME=FRAMES
/EXPRESSION= 0.17 / ( 1 / PARAMETERS::ANALOG::RATE )
/AS_INTEGER=FALSE
;
For_Each
! For each EMG channel

```



```

/ITERATION_PARAMETER_NAME=ONSET
/ITEMS=1+2+3+4+5+6+7+8
;
    Event_Threshold
    ! Create an ON event when the normalized EMG signal crosses the threshold for 0.17
sec
    ! Threshold is the average normalized signal (frames 1-10) + three times the
standard deviation
    /RESULT_EVENT_NAME=EMG_&::ONSET&_ON
    /SIGNAL_TYPES=ANALOG
    /SIGNAL_FOLDER=NORMALIZED
    /SIGNAL_NAMES=EMG_&::ONSET
    /SIGNAL_COMPONENTS=X
    ! /FRAME_OFFSET=0
    ! /TIME_OFFSET=
    ! /EVENT_SEQUENCE=
    ! /EXCLUDE_EVENTS=
    ! /EVENT_SEQUENCE_INSTANCE=0
    ! /EVENT_SUBSEQUENCE=
    ! /SUBSEQUENCE_EXCLUDE_EVENTS=
    ! /EVENT_SUBSEQUENCE_INSTANCE=0
    ! /EVENT_INSTANCE=0
    /THRESHOLD=(METRIC::EMG::EMG_&::ONSET&_BASELINE_MEAN+(3*METRIC::EMG:
:EMG_&::ONSET&_BASELINE_STDDEV))
    /ON_ASCENT=TRUE
    /ON_DESCENT=FALSE
    /FRAME_WINDOW=::FRAMES

```

```

! /ENSURE_FRAMES_BEFORE=FALSE
/ENSURE_FRAMES_AFTER=TRUE
;
Event_Threshold
! Create an OFF event when the normalized EMG signal crosses the threshold for
0.17 sec
! Threshold is the average normalized signal (frames 1-10) + three times the
standard deviation
/RESULT_EVENT_NAME=EMG_&::ONSET&_OFF
/SIGNAL_TYPES=ANALOG
/SIGNAL_FOLDER=NORMALIZED
/SIGNAL_NAMES=EMG_&::ONSET
/SIGNAL_COMPONENTS=X
! /FRAME_OFFSET=0
! /TIME_OFFSET=
! /EVENT_SEQUENCE=
! /EXCLUDE_EVENTS=
! /EVENT_SEQUENCE_INSTANCE=0
! /EVENT_SUBSEQUENCE=
! /SUBSEQUENCE_EXCLUDE_EVENTS=
! /EVENT_SUBSEQUENCE_INSTANCE=0
! /EVENT_INSTANCE=0
/THRESHOLD=(METRIC::EMG::EMG_&::ONSET&_BASELINE_MEAN+(3*METRIC::EMG:
:EMG_&::ONSET&_BASELINE_STDDEV))
/ON_ASCENT=FALSE
/ON_DESCENT=TRUE
/FRAME_WINDOW=::FRAMES

```

```

        /ENSURE_FRAMES_BEFORE=TRUE
        /ENSURE_FRAMES_AFTER=FALSE
    ;
End_For_Each
/ITERATION_PARAMETER_NAME=ONSET
;
!=====
!   Define Phase events based on "step-down" events
!=====
Select_Active_File
! Select all trials tagged left/right
/FILE_NAME=ALL_FILES
/QUERY=RIGHT + LEFT
;
For_Each
! For each phase (phases 1 through 4)
/ITERATION_PARAMETER_NAME=PHASE_CUR
/ITEMS=1+2+3+4
;
    Set_Pipeline_Parameter_From_Expression
    /PARAMETER_NAME=PHASE_END
    /EXPRESSION=::PHASE_CUR& + 1
    ! /AS_INTEGER=TRUE
    ;
    Metric_Mean
    ! Calculate the average of the normalized EMG signal from the event of P# to P#+1
    (example: P1 to P2)

```

```

/RESULT_METRIC_FOLDER=PHASE&::PHASE_CUR&
/RESULT_METRIC_NAME=_AVG
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
/SIGNAL_TYPES=ANALOG
/SIGNAL_FOLDER=NORMALIZED
!/SIGNAL_NAMES=
/SIGNAL_COMPONENTS=
/COMPONENT_SEQUENCE=ALL
/EVENT_SEQUENCE=P&::PHASE_CUR&+P&::PHASE_END&
/EXCLUDE_EVENTS=
!/SEQUENCE_PERCENT_START=0
!/SEQUENCE_PERCENT_END=100
!/GENERATE_MEAN_AND_STDDEV=TRUE
!/APPEND_TO_EXISTING_VALUES=FALSE
;

```

Metric\_Median

! Calculate the median of the normalized EMG signal from event of P# to P#+1  
(example: P1 to P2)

```

/RESULT_METRIC_FOLDER=PHASE&::PHASE_CUR&
/RESULT_METRIC_NAME=_MED
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
/SIGNAL_TYPES=ANALOG
/SIGNAL_FOLDER=NORMALIZED
!/SIGNAL_NAMES=
/SIGNAL_COMPONENTS=
/COMPONENT_SEQUENCE=ALL
/EVENT_SEQUENCE=P&::PHASE_CUR&+P&::PHASE_END&

```

```
/EXCLUDE_EVENTS=  
! /SEQUENCE_PERCENT_START=0  
! /SEQUENCE_PERCENT_END=100  
! /GENERATE_MEAN_AND_STDDEV=TRUE  
! /APPEND_TO_EXISTING_VALUES=FALSE  
;
```

End\_For\_Each

```
/ITERATION_PARAMETER_NAME=PHASE_CUR
```

```
;
```

Metric\_Mean

! Calculate the average of the normalized signal from the event P1 to P5

```
/RESULT_METRIC_FOLDER=PHASE_TRIAL
```

```
/RESULT_METRIC_NAME=_AVG
```

```
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
```

```
/SIGNAL_TYPES=ANALOG
```

```
/SIGNAL_FOLDER=NORMALIZED
```

```
! /SIGNAL_NAMES=
```

```
/SIGNAL_COMPONENTS=
```

```
/COMPONENT_SEQUENCE=ALL
```

```
/EVENT_SEQUENCE=P1 + P5
```

```
/EXCLUDE_EVENTS=
```

```
! /SEQUENCE_PERCENT_START=0
```

```
! /SEQUENCE_PERCENT_END=100
```

```
! /GENERATE_MEAN_AND_STDDEV=TRUE
```

```
! /APPEND_TO_EXISTING_VALUES=FALSE
```

```
;  
Metric_Median  
! Calculate the median of the normalized signal from the event P1 to P5  
/RESULT_METRIC_FOLDER=PHASE_TRIAL  
/RESULT_METRIC_NAME=_MED  
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE  
/SIGNAL_TYPES=ANALOG  
/SIGNAL_FOLDER=NORMALIZED  
!/SIGNAL_NAMES=  
/SIGNAL_COMPONENTS=  
/COMPONENT_SEQUENCE=ALL  
/EVENT_SEQUENCE=P1 + P5  
/EXCLUDE_EVENTS=  
!/SEQUENCE_PERCENT_START=0  
!/SEQUENCE_PERCENT_END=100  
!/GENERATE_MEAN_AND_STDDEV=TRUE  
!/APPEND_TO_EXISTING_VALUES=FALSE  
;
```

---