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The effects of leg length discrepancy on gait and balance

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ABSTRACT

Leg length discrepancy is a condition shown to affect 25-70% of the general population. The ubiquitous nature of leg length discrepancy can prove frustrating to many clinicians, particularly due to lack of consensus surrounding the amount of discrepancy that necessitates treatment.

The present research is intended to address the uncertainty surrounding diagnostic and treatment thresholds, through three related studies. In the first study, leg length discrepancy was manipulated in a sample of 15 healthy young adults, using a novel heel-to-toe lift (creating discrepancies of 5mm, 20mm, and 30mm), and the effects of this new discrepancy was observed on the spatial-temporal parameters of gait. In the second study, leg length discrepancy was again manipulated (within a sample of 40 healthy young adults) in a similar fashion to the first study, and the effects of this discrepancy on both gait and balance were observed within a dual-task paradigm, wherein attentional capacity was manipulated using an ecologically valid secondary task (dialling numbers on a cellphone). Finally, in the third study, long-term gait adaptation was measured within a sample of 100 individuals (aged 25 to 76) that had undergone an high tibial osteotomy, and who had a surgically induced leg length discrepancy from this operation. This study used leg length discrepancy as a covariate in the model, to control for the extent to which post-surgical gait changes were the result of leg length discrepancy.

Taken together, the results of these three studies provide several important pieces of clinical information: (1) small discrepancies (as small as 5mm) can disrupt gait; (2) larger discrepancies (particularly when they are qualitatively obvious to the

individual) may require conscious attention to the gait adaptation; (3) conscious gait adaptation may be be disrupted by attention-demanding secondary tasks; and (4) the effects of acquired leg-length discrepancy persist for as long as a year after they are induced.

These results are presented in the context of a "leg length accommodation model", that incorporates perceptual aspects of the leg length discrepancy, and attentional capacity (for the accommodation of the discrepancy).

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Introduction

1.1 Introduction to Leg Length Discrepancy

Leg length discrepancy (LLD) is a condition shown to affect 25-70% of

the general population (Gurney, 2002). Due to the prevalence of leg length

discrepancy, clinicians commonly test for leg length discrepancy during

standard musculoskeletal assessments. The ubiquitous nature of leg length

discrepancy can prove frustrating to many clinicians, particularly due to lack of

consensus surrounding the amount of discrepancy that necessitates treatment.

Leg length discrepancy can be broken down into structural and functional

categories. These categories of leg length discrepancy can be further divided

into 'congenital' and 'acquired' groups. It should be noted that acquired leg

length discrepancy that develops later in an individual's life (due to trauma or

surgery) is thought to be the more debilitating of the two (Gurney, 2002).

Leg length discrepancy may be particularly problematic within an aging

population. As stated by the Canadian Orthopaedic Association:

> *"It is estimated that by the year 2031, the number of people with arthritis (osteoarthritis and rheumatoid arthritis) in Canada will increase by 124%. Among individuals between 15 and 64 years of age, the prevalence of arthritis is expected to be 6.7 per cent.*
> *The prevalence of osteoarthritis is two and a half times greater than that of heart disease (3.9%) and more than six times greater than that of cancer (1.5%). A large number of Canada's 9.8 million baby boomers will likely develop osteoarthritis.*
> *The number of people age 65 and over composed only 5 per cent of the population in 1921, but by 1998 this age group totaled 12.3%-3.7 million. According to Statistics Canada projections this segment of the population is expected to expand to 15.9% (5.9 million) by 2016, 17.8% (6.9 million) by 2021 and 22.6% (9.7 million) by 2041. With this dramatic increase in our*

aging population, the need for orthopedic care will increase with it. With an increase in arthritis, falls and fractures, comes a greater need for orthopedic surgery, particularly joint replacements. More than 37,000 hip and knee joint replacements are performed in Canada each year, and the number is rising annually due to our aging population. Patients age 50 and over, based on recent statistics from the Canadian Institute for Health Information, account for 91% of hip replacement surgeries and 97% of knee replacement surgeries." (The Canadian Orthopaedic Association, 2008, page 3)

Leg length discrepancy is often a post surgical reality for the above mentioned patients. The mean leg length discrepancy for hip arthroplasty varies in the literature from 1mm to 15.4mm. The mode leg length discrepancy post hip arthroplasty has been reported at 9.7mm (Clark, Huddleston, Schoch, & Thomas, 2006).

Dr. James Herndon, in his presidential address later published in the journal of bone and joint surgery entitled "One more turn of the wrench," referenced data published by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO). JCAHO's fiduciary responsibility is to provide accounts of the types of medical errors that occur in hospitals in the United States. Out of the 19 major events described by JCAHO that demand particular vigilance, Dr. Herndon referenced six that were, in his opinion, relevant to orthopedic surgery. Included among these were patient falls and leg-length issues, which jointly accounted for 4.7% of medical errors and were recommended for study in greater detail to provide the clinician with better guidelines for treatment (Herndon, 2003).

The current cutoff for clinical significance (i.e., the point at which treatment is warranted) is a heated topic. Even though one may "reasonably assume neuromuscular control and foot loading patterns can be greatly affected by leg length discrepancy" (Perttunen, Anttila, Sodergard, Merikanto, & Komi, 2004), some authors have been bold enough to suggest that leg length discrepancy does not matter (White & Dougall, 2002). Others have suggested that smaller leg length discrepancy (as low as 3mm), combined with the compounded ground reaction forces associated with high impact activities such as running, may require treatment (Blake & Ferguson, 1992). Further to this, past literature has suggested that correction of leg length discrepancy as little as 5mm significantly reduced visual analog scales scores related to lower back pain (Friberg, 1983). Among clinicians, however, general consensus about the magnitude of discrepancy that warrants treatment appears to be 20mm. Clark et al. (2006), however, suggest that surgeons should aim for a post-arthroplasty leg length discrepancy (either lengthening or shortening) of 7mm.

Providing an enhanced understanding of the affects of leg length discrepancy both small and large, will aid in guiding clinicians toward effective patient treatment and referral.

1.2 Etiology & Demographics

Limb length discrepancy, or anisomelia, is a condition defined as a paired set of limbs that are unequal (Gurney, 2002). When this unequal pairing of limbs occurs in the lower extremity, anisomelia is known clinically as a leg length discrepancy. Leg length discrepancy can be further subdivided into two

etiological categories: functional leg length discrepancy, and structural leg

length discrepancy (Gurney, 2002).

Functional leg length discrepancy is described as a discrepancy caused

by an asymmetry in soft tissue, giving the appearance of a discrepancy (Gurney,

2002). This asymmetry may be caused by the effects of muscle or joint

tightness in the lower kinetic chain (Hanada, Kirby, Mitchell, & Swuste, 2001).

Common causes of functional leg length discrepancy are asymmetries in

strength, flexibility, and asymmetrical subtalar joint pronation or supination that

may cause an increase or decrease (respectively), in rotational torques in the

affected limb (Gurney, 2002).

Structural leg length discrepancy is defined as a discrepancy due to an

osseous malformation of the load bearing bones or a simple difference among

the lower extremities, in either the femur, the tibia, or both (Gurney, 2002).

Etiology of structural leg length discrepancy is attributed to, but not limited to:

congenital dislocation of the hip, fractures, avascular necrosis of the femoral

head, infections, tumors, and surgical procedures such as a total hip

arthroplasty.

1.3 Clinical Significance

Structural leg length discrepancy, and the alterations in biomechanical

function that is associated with it, is thought to be a contributing factor to many

clinical pathologies (Friberg, 1984; Giles & Taylor, 1981; Gurney, 2002; Hanada,

et al., 2001; Kakushima, Miyamoto, & Shimizu, 2003; Walsh, Connolly,

Jenkinson, & O'Brien, 2000). These pathologies include lower back pain,

osteoarthritis of the hip, aseptic loosening of hip prostheses, lower limb stress fractures, knee pain, and poor running economy. Many authors have linked leg length discrepancies to these pathologies by way of the compensatory mechanisms developed by the patient (Friberg, 1983; Giles & Taylor, 1981; Kakushima, et al., 2003; Kaufman, Miller, & Sutherland, 1996; Papaioannou, Stokes, & Kenwright, 1982).

The leg length discrepancy literature is typified by a general lack of agreement as to the point at which treatment is warranted. Blake et al. (1992) reported that a leg length discrepancy of only 3mm can be clinically relevant to runners due to the increase in ground reactive forces upon heel strike, and Friberg (1983) reported that a 5mm leg length discrepancy is enough to be a contributing factor in the development of low back pain. White et al. (2002) reported, however, that a leg length discrepancy of up to 19mm was acceptable.

1.4 Measurement of Leg Length Discrepancy

Medical Imaging

Scanogram is a common method utilized by clinicians (Beattie, Isaacson, Riddle, & Rothstein, 1990). A scanogram is an x-ray that captures the hip, knee, and ankle, non-weight bearing in three separate exposures. A radiographic ruler is placed in the midline of the patient's body so that measurements may be taken right off the x-ray. Compared to traditional x-ray, the scanogram lessens the chance of magnification error, but does increase the cost of the procedure, as well as the patient's exposure to radiation (Beattie, et al., 1990). Also, determinations of leg length from a scanogram only account for the overall

structural length of the femur and tibia, and may not take into account functional leg length or the differences in joint space that may be present.

Computerized tomography (CT) has also been utilized in the detection of leg length discrepancy (Tokarowski, Piechota, Wojciechowski, Gajos, & Kusz, 1995). CT has been shown to have a precision of less than 1mm with 66% less radiation exposure to the patient when compared to radiograph (Porat & Fields, 1989). Although CT is more reliable (and arguably safer) than x-ray, it is used less often due to the cost of the procedure, and the longer wait times that are typically seen for CT (Tokarowski, et al., 1995).

Physical Measurements

Some researchers argue that imaging techniques are costly, time consuming, and may expose the patient to unneeded radiation (Beattie, et al., 1990). Due to the aforementioned factors, different measurement protocols have been developed to measure leg length discrepancy.

The tape measure method is a method described often in the literature as an alternative way to measure structural leg length discrepancy (Beattie, et al., 1990). This method involves taking a measurement from the individual's anterior superior iliac spine to the medial malleolus, while the individual is supine on a plinth. The tape measure method is subject to errors due to differences in circumference between the lower extremities, and unilateral deviations along the long axis of the leg, such as genu valgum or varum. Furthermore, pelvic differences, and difficulty land-marking boney prominences (such as the anterior

superior iliac spine) might prove to be difficult, and contribute to error (Eichler, 1972).

To investigate the real impact of this error variation, Beattie et al. (1990) measured nineteen individuals (10 individuals with a leg length discrepancy and nine controls) from the anterior superior iliac spine to the medial malleolus, using the tape measure method, and then compared this measurement to mini-scanogram (non-weight bearing radiograph). Beattie et al. (1990) reported intraclass correlation coefficients of 0.68 for both groups when only one measurement was taken. When the means of two measurements were compared however, this association increased to 0.79, suggesting that the tape measure method demonstrates acceptable concurrent validity.

1.5 Kinematic Effects of Leg Length Discrepancy

Walsh et al. (2000) studied the effect of leg length discrepancies on the lower kinetic chain by simulating leg length discrepancies from 0-5cm on seven normal subjects (Walsh, et al., 2000). The measurement used to determine the possibility of a leg length discrepancy was defined as a "clinical method," but not described in full. The leg length discrepancy was simulated by way of attaching a heel lift orthotic device to the participant's foot at 1-5cm intervals, and the participant underwent 3D gait analysis. Walsh et al. (2000) reported kinematic changes in the pelvis, knee, and foot (for a full description of kinematic variables used in this - and other similar studies - please refer to Appendix A). Walsh et al. (2000) reported that, when walking, the pelvis on the longer leg displayed an increase in obliquity, tilting up to the longer side. The hip

and knee both showed an increase in flexion on the longer side, and the foot and ankle compensated for the longer leg two different ways. The ankle showed an increase in dorsiflexion, and the subtalar joint of the longer leg displayed more pronation (Walsh, et al., 2000).

On the shorter side of the discrepancy, Walsh et al. (2000) reported that the main compensation was an increase in knee extension. The ankle's compensatory mechanism on the short leg was reported to be increased plantarflexion. Walsh et al. (2000) reported that all of the kinematic changes in the lower extremity increased gradually with the increase of leg length discrepancy. Plantarflexion of the ankle, however, was shown to be sensitive to very small changes in discrepancy. Walsh et al. (2000) reported that the pathomechanical role of these compensatory mechanisms might be an explanation for the role of leg length discrepancies in the presenting pathology of the hip, knee, and ankle (Walsh, et al., 2000).

To further elucidate the role of leg length discrepancy in the pathomechanics of injury, Kakushima et al. (2003) studied the effects of leg length discrepancies on spinal motion during gait. Twenty-two normal subjects were studied with a heel-lift-simulated 3cm leg length discrepancy. The method used to rule out leg length discrepancy pathology in participants was not outlined. The findings of Kakushima et al. (2003) suggested that asymmetric lateral bending of the spine toward the short side, and an increase in bending velocity, is a compensatory mechanism of leg length discrepancy during gait. They also reported that people with leg length discrepancy might be at greater

risk of developing disabling spinal disorders due to exaggerated degenerative change (Kakushima, et al., 2003).

1.6 Ecological Validity of Various Methods of Inducing Leg Length Discrepancy

In the aforementioned studies, induced leg length discrepancy has been studied by way of attaching a heel lift to the participants' shoe and/or foot. Although this does raise the heel (and produces a leg length discrepancy), the primary clinical phenomenon studied with a heel-only raise is ankle equinus, and so this is not an ecologically valid leg length discrepancy. At terminal stance phase of gait, as the heel is lifting (thereby shifting pressure to the forefoot), not only is the ankle in forced plantarflexion from the heel lift, the forefoot is not in the position it would be if the leg length discrepancy were created by organic methods described in section 1.2.

Biomechanical abnormalities specific to equinus deformity have previously been described (Higginson et al., 2006). Higginson et al. (2006) studied the effect of induced equinus on knee extension during gait. The researchers induced the equinus by lifting a participants' heel to place the ankle in 20 degrees of plantarflexion. The results reported were of significant knee hyperextension on the induced equinus leg, and the change in knee mechanics was likened to a change in the location of the centre of pressure of the ground reaction force to be more anteriorly on the foot. This change resulted in an unbalanced net external knee extension moment. These results call into

question the methodology of inducing leg length discrepancy by way of a heel-only lift.

Interestingly, the heel-only lift is the only method of inducing leg length discrepancy that has been reported in the literature. To date, no other research has attempted to experimentally induce leg length discrepancy through the use of full heel-to-toe lifted shoes (the method used within this dissertation).

1.7 Temporal-Spatial Effects of Leg Length Discrepancy

A review of both Scopus and Pubmed yielded only one relevant study pertaining to the temporal-spatial effects of leg length discrepancy during gait. Not surprisingly, this article noted the rarity of the use of EMG and plantar pressure measurements in the bilateral comparison of participants with leg length discrepancy (Perttunen, et al., 2004). They studied the plantar pressure effects of leg length discrepancy on 25 children with a range of discrepancy from 1.7-5cm. The findings of this study suggested that the stance phase of gait was significantly shortened on the short leg, at both normal and fast walking speeds. Furthermore, plantar pressures under the heel, and under the hallux, were recorded at statistically significant higher rates on the long limb side. Measures of medial forefoot pressure were found to be higher on the short limb side. Perttunen et al. (2004) concluded that uncorrected leg length discrepancy may lead to pathological loading of the spine and lower extremity. Furthermore, better understanding of temporal spatial parameters will aid clinicians in the planning of procedures to prevent and correct possible degenerative changes in patients with leg length discrepancy.

This study illustrates that temporal-spatial analysis, as it relates to clinical understanding and planning, is a useful tool in providing clinicians with information regarding the measurement of moderate leg length discrepancy. When measured with a high degree of accuracy, temporal-spatial measures of gait provide useful diagnostic and therapeutic information in a clinical setting (Webster, Wittwer, & Feller, 2005). Although three-dimensional motion analysis can be very precise in its description of joint and limb movements (and can therefore be used to estimate temporal-spatial variables), it tends to be significantly more expensive than pressure-based assessments of temporal-spatial variables, is more time consuming to use (both in the collection and the analysis of data), and is not easily portable from location to location. Thus, this form of measurement is impractical within most clinical settings (Webster, et al., 2005).

1.8 Validity and Reliability of Temporal Spatial Gait Measures

The GAITRite system has been developed to accurately measure temporal-spatial parameters of gait with an automated software program, to reduce cost without a marked reduction in clinically relevant information. Stride length is measured at the center of the heel on one foot to the same spot on the same foot after consecutive steps. Step length is measured by the center of the heel on one foot to the center of the heel on the previous foot on the opposite side. Toeing angle is measured by the midline of the foot and the line of progression. Step time is measured by the initial contact of one foot to the initial contact of the opposite foot. Stance time is measured by the initial contact to

heel lift of one step. Velocity is measured by distance by time. Single support is measured by the last contact of the current step to the initial contact of the second step on the same foot. Double limb support is measured by the time both feet are making contact with the floor.

GAITRite has shown excellent overall reliability and validity (Chien et al., 2006; Nelson et al., 2002), demonstrating good concurrent validity when measured against a three-dimensional motion capture system (Webster, et al., 2005). Webster et al. (2005) compared GAITRite to a Vicon-512 motion capture system that consisted of six infrared cameras, sampling at a rate of 50Hz, calibrated to manufacturer specifications. Averaging steps across one walk along the GAITRite walkway, they reported no statistically significant differences on any of the gait parameters (velocity, cadence, step length, and step time) and also found intraclass correlation coefficients ranging from 0.92 to 0.99, thus indicating a high level of agreement between the GAITRite and Vicon systems. Step-to-step measures of step length and step time were also highly correlated between the GAITRite and the Vicon motion-capture system, with ICCs of 0.99 and 0.91, respectively. Given that Webster et al. (2005) utilized a clinical sample (a group of individuals that had undergone joint replacement surgery), these results are highly suggestive of a good clinical utility for the GAITRite system.

Menz et al (2003) evaluated the test-retest reliability of the GAITRite with a sample of 61 subjects. Thirty of the participants were young adults (*M=28.5, SD=4.8)*, and the remaining 31 were older adults (*M=80.8, SD=3.1)*. Walking speed, cadence, and step length all showed excellent ICCs within both groups

of participants, ranging from 0.82-0.92. Although most measures were shown to

have high ICCs, the authors reported that the ICCs for base of support and toe

in/out angles were generally lower within the older population (0.49-0.82) when

compared to that of the younger (0.85-0.94) (Menz, Latt, Tiedemann, Mun San

Kwan, & Lord, 2004).

van Uden et al. (2004) studied test-retest reliability on 21 healthy subjects

and reported significant ICCs across all temporal-spatial parameters collected

(0.79-0.98) and between normal and fast paced walking with base of support

showing the lowest score (van Uden & Besser, 2004). While the authors of both

studies suggested caution in the interpretation of the base of support and toe in/

out parameters, both also concluded that the GAITRite system is a reliable tool

for temporal-spatial measurements.

1.9 Dual Task Paradigms

 Performance of one task simultaneously with another is common

throughout everyday life. Walking while dialing, or talking on, a cellular phone

are examples of such dual-tasking activity. The dual task paradigm has been

utilized by researchers to study the effects of a secondary, attention demanding

activity (such as talking) on an attention demanding primary task (such as

walking). Further, a primary task can be described as the task providing the

performance measure on which attentional demands will be made, and the

secondary task providing the attentional diverting stimulus: ie: walking while

dialing a cellular phone.

 If the execution and maintenance of gait is attention-demanding, the

addition of a secondary demanding task will produce interference when

attentional capacity is exceeded. "Dual task interference" can be defined as a

decline in performance in one or both attention demanding tasks (Woollacott &

Shumway-Cook, 2002). Models of dual task interference have been previously,

and elegantly described in the literature. One such model that seeks to explain

interference has been proposed by Huang and Mercer (2001) called the

"bottleneck model" The bottleneck model suggests that when two types of

interference, that tax similar pathways, compete for attentional resources a

'bottleneck' of information occurs and interference will arise. The "crosstalk

model" is contrary to that of the bottleneck model insofar as it suggests that

information that utilize that same pathways will tax attentional resources less

and therefore will enhance performance by reducing interference (O'Shea,

Morris, & Iansek, 2002).

A third model related to dual tasking, and the one followed in this thesis,

is the "resource sharing model" (O'Shea, et al., 2002). The researchers

explained that interference is the result of central overload when two seemingly

separate tasks compete for limited attentional resources, thus exceeding central

processing capacity (Huang & Mercer, 2001). The aforementioned model is

highly dependant on the complexity of the secondary task, with tasks of higher

complexity demanding more attentional resources, draining central processing.

Evidence of this effect of complexity was shown by Bloem et al. (2001) who

suggested that motor errors increased as task complexity increased in a population of older adults (Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001).

Furthermore, the resource sharing model was suggested by Armieri et al. (2009) when they studied dual tasking effects on temporal spatial gait measures. The researchers assigned a cognitive secondary task (a "digit span" task) to healthy young participants, and measured the subsequent changes in the participant gait across increasing levels of cognitive complexity, within the secondary task. All parameters of gait demonstrated a statistically significant effect of cognitive complexity, suggesting that the greater the "cognitive load", the more impairment that will be demonstrated within the primary gait task (Armieri, Holmes, Spaulding, Jenkins, & Johnson, 2009).

1.9.1 Dual Task Interference on Temporal-Spatial Gait Parameters

As described in the preceding section, dual task interference, and the effect of complexity, has been shown to affect temporal spatial gait on healthy young participants. The effects of dual tasking on gait in a population with leg length discrepancy has not yet been studied. Given that dual-task interference has been suggested to produce significant changes in temporal-spatial parameters of gait, it is anticipated that dual-task interference will exacerbate gait dysfunction that results from induced leg length discrepancy. If accommodations to gait are required in people who have a discrepancy, it is theorized that these accommodations will require and divert conscious attention, with larger discrepancies requiring a greater amount of attention than smaller discrepancies.

1.9.2 Dual Task Interference on Posture

Riley et al. (2003), studied the effect of digit recall (easy, medium, and difficult) on the standard deviation of the centre of pressure time series in the anterior / posterior, medial / lateral axes, and centre of pressure path length (COPL) while healthy young participants were standing on a destabilized force plate. Care was taken to avoid possible confounders such as vocal, motoric, or ocular responses that might influence postural changes as the digit recall was recorded post data collection. The researchers concluded that sway variability in the anterior / posterior axis was reduced significantly when participants performed the digit rehearsal task under more difficult conditions **(Riley, Baker, & Schmit, 2003)**.

The effects of dual tasking on balance in a population with leg length discrepancy has not yet been studied. Given that dual-task interference has been suggested to produce significant changes in gait and balance, and that some researchers have proposed that gait and posture are inextricably linked due to the fact that the successful maintenance of gait requires ongoing postural adjustment (Shkuratova, Morris, & Huxham, 2004), it is anticipated that dual-task interference will exacerbate balance dysfunction that results from induced leg length discrepancy.

1.10 The Present Research

What we hope to derive out of this research, and thus contribute to the literature, is a novel leg length discrepancy accommodation model that seeks to

explain the accommodation strategy used by individuals with leg length discrepancy.

Three related studies are presented within this thesis. In the first study, leg length was manipulated within a healthy young population in a novel, and ecologically valid way, by way of heel-to-toe lifted footwear. The effects of this systematic manipulation of leg length discrepancy were then evaluated using temporal-spatial parameters of gait, assessed using a GaitRITE instrumented carpet. Three lift heights were used: one very subtle discrepancy (5mm), and two discrepancies that were expected to produce qualitatively obvious sensations of leg length asymmetry. It was hypothesized the measured gait disruptions will increase with the magnitude of the discrepancies, per the findings of Walsh et al. (2000).

In the second study, leg length discrepancy was once again manipulated within a healthy population, using the ecologically valid methodology developed in the first study. The second study was designed to evaluate the extent to which any conscious (or intentional) compensatory gait strategies would be affected by a manipulation of attentional resources. We chose a dual-task interference paradigm for our method of manipulating attentional resources, owing to the ubiquity of dual-tasking within activities of daily living. Further to this, we employed an ecologically valid secondary task (holding, looking at, and dialing a cellular phone). It was hypothesized that the dual-task interference arising from cellular phone usage would exacerbate any gait dysfunction resulting from the induced leg length discrepancy. Specifically, we expected

that any compensatory mechanisms employed in the control of the qualitatively obvious leg length discrepancies would be overwhelmed by the complexity of the secondary task, and that there would be a significant interaction between lift height and task complexity. This study represents the first attempt at examining the effects of dual-task interference on the gait disturbances produced by leg length discrepancy.

Finally, in the third study, gait alteration of people with surgically acquired (i.e., pursuant to a high tibial osteotomy) leg length discrepancy was studied using a 3D motion capture system. To estimate the impact of the acquired discrepancy, leg length discrepancy was analyzed as a covariate within the model. This use of an ANCOVA model allows for the examination of the observed changes that may be attributed to surgery, and also allows for a control of the variability that may be attributed to leg length discrepancy. Despite the fact that virtually all individuals who undergo high tibial osteotomy will experience a leg length discrepancy, there are no published studies that have attempted to isolate the variability in post-surgical outcomes that is due to leg length discrepancy.

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Chapter 2:

The Effect of Artificially Induced Leg Length Discrepancy on

Temporal and Spatial Parameters of Gait[1]

2.1 Introduction

Leg length discrepancy is a condition that has been shown to affect 25-70% of the general population (Gurney, 2002). Due to the prevalence of leg length discrepancy, clinicians commonly test for leg length discrepancy during standard musculoskeletal assessments. The ubiquitous nature of leg length discrepancy can prove frustrating to many clinicians, particularly due to lack of consensus surrounding the amount of discrepancy that necessitates treatment.

Leg length discrepancy can be broken down into structural and functional categories. These categories of leg length discrepancy can be further divided into 'congenital' and 'acquired' groups. It should be noted that acquired leg length discrepancy that develops later in an individual's life (due to trauma or surgery) is thought to be the more debilitating of the two (Gurney, 2002).

Leg length discrepancy is often a post-surgical reality for patients who have undergone total hip and knee arthroplasty. The mean leg length discrepancy for hip arthroplasty varies in the literature from 1mm to 15.4mm. The mode leg length discrepancy post hip arthroplasty has been reported at 9.7mm (Clark, Huddleston, Schoch, & Thomas, 2006).

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[1] A version of this chapter has been submitted for publication: Dombroski, C. & Johnson, A.M. (under review). The effect of artificially induced leg length discrepancy on temporal and spatial parameters of gait. *Gait and Posture.*

The current cutoff for clinical significance (i.e., the point at which treatment is warranted) is a heated topic. Even though it is reasonable to assume that neuromuscular control and foot loading patterns are affected by leg length discrepancy (Perttunen, Anttila, Sodergard, Merikanto, & Komi, 2004), some authors have been bold enough to suggest that leg length discrepancy does not matter (White & Dougall, 2002). Others have concluded that smaller leg length discrepancy (3mm), combined with the compounded ground reaction forces associated with running, may require treatment (Blake & Ferguson, 1992). Furthermore, research has suggested that correction of leg length discrepancies as small as 5mm significantly reduced self-reported lower back pain (Friberg, 1983). Among clinicians, however, the general consensus as to the magnitude of discrepancy that warrants treatment appears to 20mm, with Clark et al. (2006) suggesting that surgeons should aim for a post-arthroplasty leg length discrepancy (either lengthening or shortening) of 7mm.

Previously, induced leg length discrepancy has been studied by way of attaching a heel lift to the participants' shoe and or foot. Although this does raise the heel, the primary clinical phenomena studied with a heel-only raise is an ankle equinus, and not an ecologically valid leg length discrepancy.

Biomechanical abnormalities specific to equinus deformity have previously been described. Higginson et al. (2006), studied the effect of induced equinus on knee extension during gait. The researchers induced the equinus by lifting a participants' heel to place the ankle in 20 degrees of plantarflexion. The result of this intervention was significant knee hyperextension on the induced

equinus leg, resulting in a change in the centre of pressure of the ground reaction forces, such that it was located more in the anterior of the foot. This resulted in an unbalanced net external knee extension moment. These results call into question the methodology of inducing leg length discrepancy by way of a heel-only lift.

The present study investigated the alterations in spatial-temporal parameters of gait (e.g., step length, step time, double-leg support time, etc.) that occurred as a direct result of an artificially induced leg-length discrepancy in healthy young adults. This is the first study to investigate spatial-temporal properties of gait in a population of individuals that have both small and large ecologically valid leg-length discrepancies.

2.2 Methods

2.2.1 Participants

Fifteen healthy young adults between the ages of 18-40 (Male=6, Female=9) were recruited at the University of Western Ontario. Participants were excluded from the study if they had a pre-existing leg length discrepancy (functional, or structural with a tolerance of 0 LLD), scoliosis, were severely overweight (BMI>30), or had significant lower limb pathology.

2.2.2 Instrumentation

Spatial-temporal parameters of gait were quantified using a 20-foot GAITRite electronic walkway. The GAITRite system contains 13,824 pressure sensors and uses a proprietary software package to aggregate and calculate gait parameters. The parameters of interest within the present study were

velocity, step time, stance time, single limb support, double limb support, step length, base-of-support, and toeing.

2.2.3 Procedure

All participants were assessed by a Canadian certified pedorthist (C.D) in order to ascertain study eligibility (per the aforementioned exclusion criteria), including whether or not a substantive leg length discrepancy existed. Each participant's legs were measured, using the tape measure method described by Beattie (1990). The tape measure method is described often in the literature as an alternative way to measure structural leg length discrepancy (Beattie, et al., 1990). This method involves taking a measurement from the individual's anterior superior iliac spine to the medial malleolus, while the individual is supine on a plinth. The tape measure method is subject to errors due to differences in circumference between the lower extremities, and unilateral deviations along the long axis of the leg, such as genu valgum or varum. Beattie et al. (1990) reported intraclass correlation coefficients of 0.68 for both groups when only one measurement was taken. When the means of two measurements were compared however, this association increased to 0.79, suggesting that the tape measure method demonstrates acceptable concurrent validity.

Although the current gold standard of leg length measurement is the scanogram (which is a three film x-ray of both limbs, allowing for measurement), the mean of two tape measurements has been demonstrated to objectively alert the examiner to the existence of a leg length discrepancy (Beattie, et al., 1990). Of the 20 volunteers originally assessed for this study, only 15 met the criteria.

All five of the individuals who failed to meet the exclusion criteria were excluded due to a putative leg length discrepancy, as identified by the tape measure method.

To artificially induce leg length discrepancy, a Pedors post-surgical shoe was modified with 65 shore A durometer ethel vinyl acetate added to the midsole of the shoe. This created three different discrepancies (5mm, 20mm, and 30mm), using currently accepted pedorthic procedures (Janisse & Janisse, 2008).

All participants completed the walking trials on a computerized data-collecting and pressure-sensitive surface (GAITRite®, CIR Systems, Inc., Clifton, NJ, USA) within a large, clutter-free laboratory. Participants were placed in the baseline shoes (no lift) and were instructed to walk clock-wise around the GAITRite carpet at a self selected pace, for 3 complete circuits, to acclimatize to the new shoe. After this acclimatization period, a total of 5 walking trials along the GAITRite (also at a self-selected pace) were used to collect baseline data. After the baseline data was collected, leg-length discrepancy was manipulated using the three different shoes described above with with participant's right foot always receiving the lifted shoe. To control for order bias, the experimental blocks (i.e., the three different lifts) were randomized. Five walking trials were collected within each experimental block.

2.2.4 Statistical Analysis

Gait velocity was analyzed using a single-factor analysis of variance (ANOVA), with lift (0mm, 5mm, 20mm, and 30mm) as the independent variable.

All other spatial-temporal gait parameters were analyzed within a 2x4 repeated

measure multivariate analysis of variance (MANOVA) using side (left versus right)

and lift (0mm, 5mm, 20mm, and 30mm) as the within-subject factors. Two

"families" of comparisons were used in this study - temporal variables and

spatial variables - and separate MANOVAs were computed for each of these

families of comparisons. To control for multiple comparison bias, the

multivariate effect within each MANOVA was evaluated, prior to the

interpretation of the univariate effects, and each MANOVA was evaluated at an

alpha of 0.025 (given that the analysis was divided into two families of

comparison). To control for minor violations of sphericity, the Greenhouse-

Geisser epsilon adjustment was applied (where appropriate) to degrees of

freedom estimates.

2.3 Results

Descriptive statistics for all dependent variables are presented in Table

2.1. There was a significant effect for velocity [$F(2.282, 31.942) = 8.888$,

$p<0.001$, $\eta^2_{partial} = .388$] suggesting that lift has a significant effect on gait

velocity. Post hoc testing (via simple contrasts) for velocity revealed that 5mm

and 20mm lifts were significantly different from baseline (i.e., no lift), while the

30mm lift was not.

Within the MANOVA conducted on the temporal gait parameters (step

time, stance time, single limb support time, and double limb support time), the

multivariate effect of the interaction between side and lift was statistically

Table 2.1 Means (and standard deviations), separated by lift height and side, across all gait parameters

Temporal / Spatial Gait Parameters

	Velocity (cm/s)	Step Time (s)		Stance Time (s)		Single Limb Support (s)		Double Limb Support (s)		Step Length (cm)		BOS (cm)		Toeing (cm)	
		L	R	L	R	L	R	L	R	L	R	L	R	L	R
0mm Lift	131.300 (10.141)	.567 (.027)	.559 (.027)	.696 (.037)	.706 (.033)	.420 (.024)	.422 (.022)	.275 (.026)	.274 (.027)	74.114 (6.385)	73.662 (6.777)	9.703 (2.044)	9.842 (2.079)	4.400 (3.059)	6.280 (4.430)
5mm Lift	139.500 (12.374)	.544 (.030)	.546 (.030)	.673 (.037)	.672 (.036)	.417 (.027)	.411 (.035)	.257 (.026)	.258 (.026)	76.050 (6.940)	75.950 (7.959)	10.077 (2.237)	9.948 (2.416)	4.053 (3.366)	7.387 (3.756)
20mm Lift	136.467 (13.001)	.556 (.028)	.544 (.032)	.677 (.042)	.683 (.039)	.418 (.025)	.417 (.023)	.260 (.029)	.262 (.029)	74.399 (6.794)	75.779 (7.498)	11.240 (2.126)	11.244 (2.310)	4.420 (3.583)	6.493 (4.003)
30mm Lift	135.233 (13.538)	.568 (.031)	.542 (.031)	.678 (.037)	.692 (.038)	.419 (.029)	.426 (.027)	.261 (.027)	.261 (.026)	73.662 (6.777)	76.670 (7.902)	11.033 (2.131)	11.125 (2.101)	3.930 (3.739)	7.673 (4.993)

significant [$F(12, 123) = 4.099$, $p<0.001$, $\eta^2_{partial} = .713$]. Similarly, the

multivariate effect for the interaction between side and lift was statistically

significant for the spatial variables (step length, base-of-support, and toeing), [$F(9, 126) = 6.856$, $p<0.001$, $\eta^2_{partial} = .764$]

Univariate analyses of the interaction between side and lift are presented

in Table 2.2 for all spatial and temporal variables. Step time, stance time, single

limb support time, step length, and toeing all demonstrated a statistically

significant interaction, suggesting that the effects of lift height differ between the

long (right) and short (left) legs. Neither double-limb support time, nor base of

support, demonstrated a statistically significant interaction effect.

Post hoc tests of the lift by side interaction (using simple contrasts) are

also presented in Table 2.2, for each of the spatial and temporal variables. For

step time, both the 5mm and 30mm lifts were shown to have significantly

different effects (relative to the baseline condition) across the two legs.

Interestingly, while step time appeared to be affected by the 5mm lift in both

limbs, the 30mm lift produced a slower step time in the longer leg only.

Furthermore, participants had a shorter stance time, and spent less time in

single-limb support, in their longer leg, when comparing the 5mm lift to baseline.

Finally, considering the spatial variables, significant left-right differences were

seen for the step length variable, when comparing the 20mm lift to baseline, and

the 30mm lift to baseline, and for the toeing variable when comparing the 5mm

and 30mm lifts to baseline. In both of these variables, the effect was seen to a

Table 2.2. Univariate effects for the interaction between lift and side for all temporal and spatial variables, with post-hoc tests (simple contrasts) for each variable that demonstrated a statistically significant effect of the interaction.

Parameter	F-ratio (df) for interaction between side and lift	Post Hoc Comparisons F-ratio (partial eta-squares)		
		Baseline vs. 5mm	Baseline vs. 20mm	Baseline vs. 30mm
Velocity	$F(2.282,31.942)=8.888$, $p=0.001$, $\eta^2_{partial}=0.388$	*26.139 (0.651)*	*7.779 (0.357)*	*3.993 (0.222)*
Step Time	$F(2.408,33.708)=22.925$, $p<0.001$, $\eta^2_{partial}=0.621$	*4.346 (0.056)*	*1.729 (0.110)*	*24.271 (0.634)*
Stance Time	$F(2.828,39.596)=7.474$, $p<0.001$, $\eta^2_{partial}=0.348$	*12.674 (0.475)*	*1.479 (0.096)*	*1.503 (0.097)*
Single Limb Support	$F(2.506,35.078)=8.257$, $p<0.001$, $\eta^2_{partial}=0.371$	*11.051 (0.441)*	*0.764 (0.052)*	*1.503 (0.169)*
Double Limb Support	$F(2.500,34.997)=1.119$, $p<0.348$, $\eta^2_{partial}=0.074$			
Toeing	$F(2.217,31.037)=7.205$, $p=0.002$, $\eta^2_{partial}=0.34$	*18.484 (0.569)*	*0.106 (0.007)*	*10.294 (0.424)*
Step Length	$F(2.113,29.577)=25.053$, $p<0.001$, $\eta^2_{partial}=0.642$	.501 (0.035)	*10.281 (0.423)*	*35.636 (0.718)*

Note: significant contrasts are indicated in italics.

much greater extent in the longer leg, with step length being longer (for both the 20mm and 30mm lifts), and toeing being more positive (for both the 5mm and 30mm lifts). These effects are also presented graphically in Figures 2.1 through 2.6.

2.4 Discussion

It is clear from the results of this study that induced leg length discrepancies of 5mm produced the largest disruptions in 4 of 6 significant temporal-spatial parameters studied. WIth respect to velocity, the smallest lift, 5mm, produced the largest change in gait velocity, speeding gait. As lift height increased, gait velocity began to regress back toward, however not fully reaching, the baseline value.

The largest lift, 30mm, produced the largest step time difference, slowing step time overall. On the non-affected side or the induced "short leg" step time regressed back to baseline values. Step time became increasingly slower for the affected, or induced "longer" limb. The largest change in stance time was observed with the smallest lift, 5mm. Stance time, in both legs, regressed back toward baseline values; however the induced short leg did not regress back as much. Overall, stance time was reduced, in both legs, the greatest with the smallest amount of lift, 5mm, with the induced longer leg recovering more than the shorter. Single limb support, showed a significant reduction with the smallest lift, 5mm.

The effects of lift on step length were the greatest at 20 and 30mm of lift. Toeing demonstrated a difference with both 5mm and 30mm of lift, with 5mm

Figure 2.1. Gait velocity (in centimetres per second), as a function of lift height.
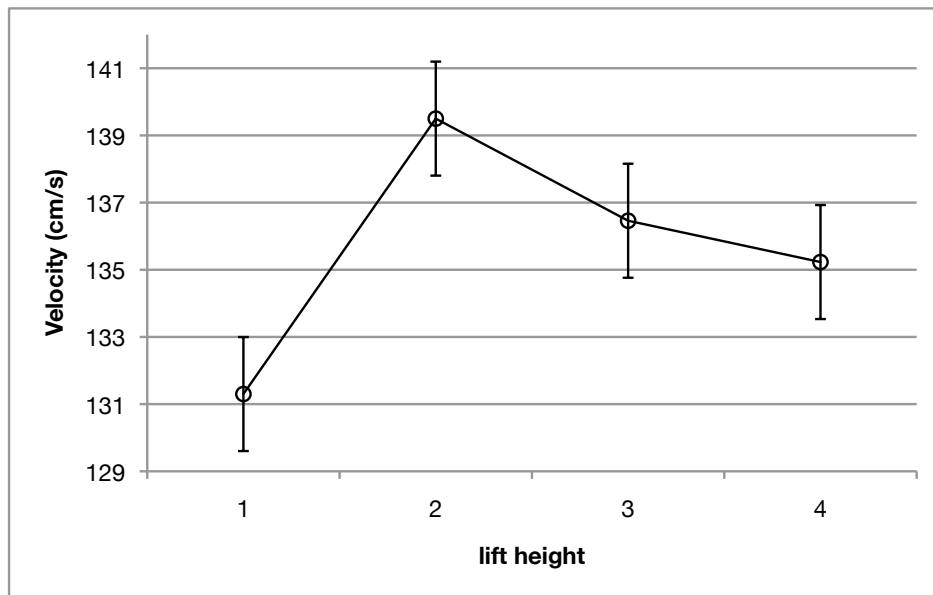
Note: Lift height: 1: *No lift*; 2: *5mm*; 3: *20mm*, 4: *30mm*

Figure 2.2. Step time (in seconds), as a function of lift height, separated by side (short versus long leg)
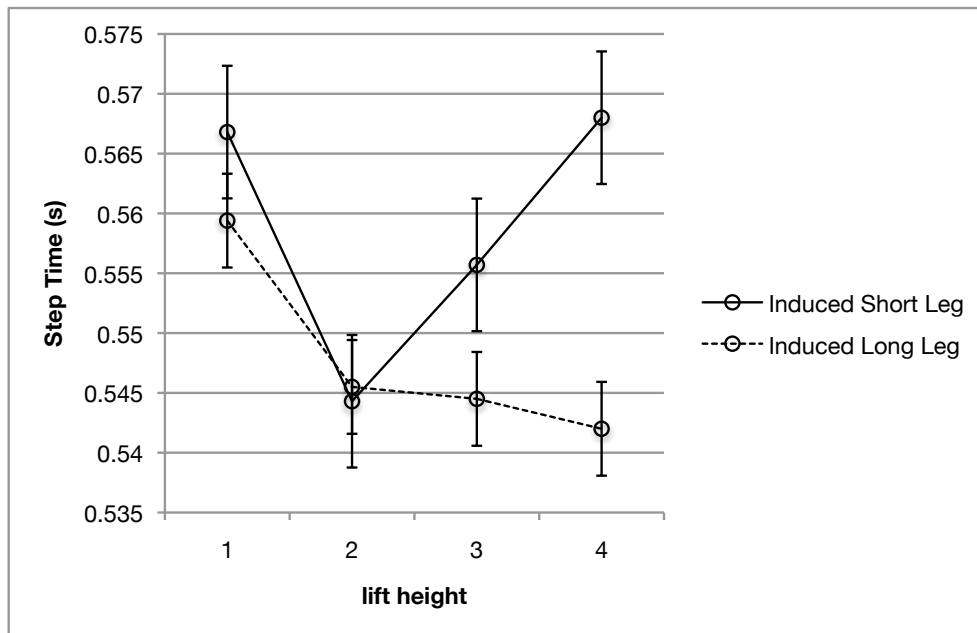
Note: Lift height: 1: *No lift*; 2: *5mm*; 3: *20mm*, 4: *30mm*

Figure 2.3. Stance time (in seconds), as a function of lift height, separated by side (short versus long leg)
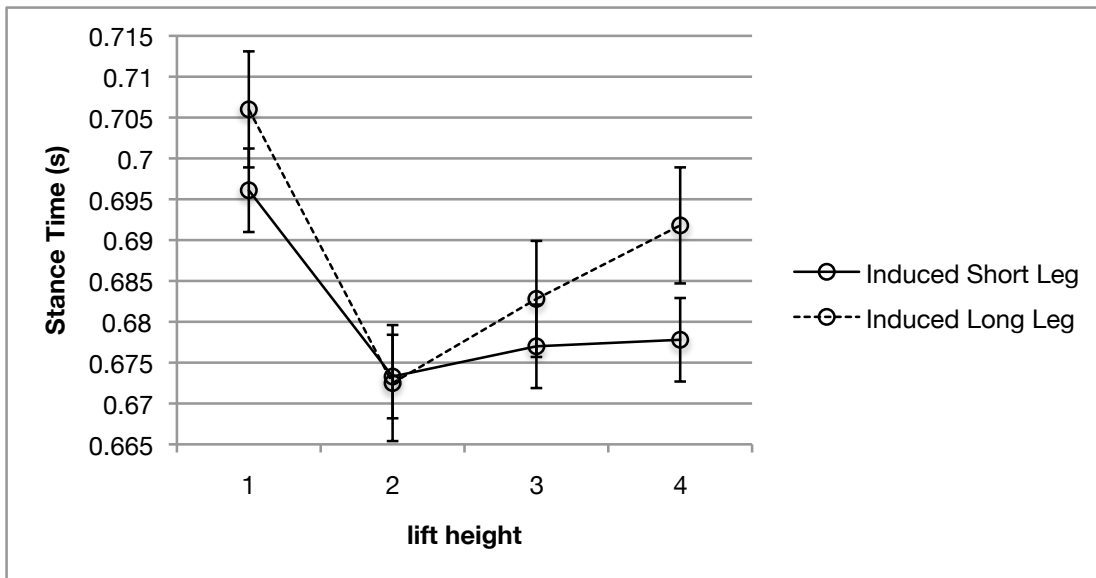
Note: Lift height: 1: *No lift*; 2: *5mm*; 3: *20mm*, 4: *30mm*

Figure 2.4. Single limb support time (in seconds), as a function of lift height, separated by side (short versus long leg)
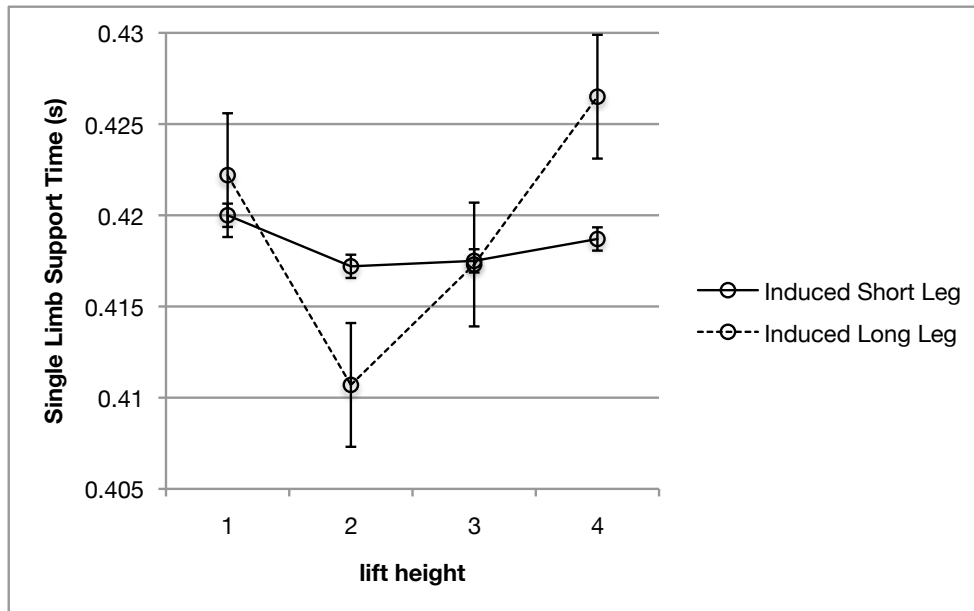
Note: Lift height: 1: *No lift*; 2: *5mm*; 3: *20mm*, 4: *30mm*

Figure 2.5. Step length (in centimetres), as a function of lift height, separated by side (short versus long leg)
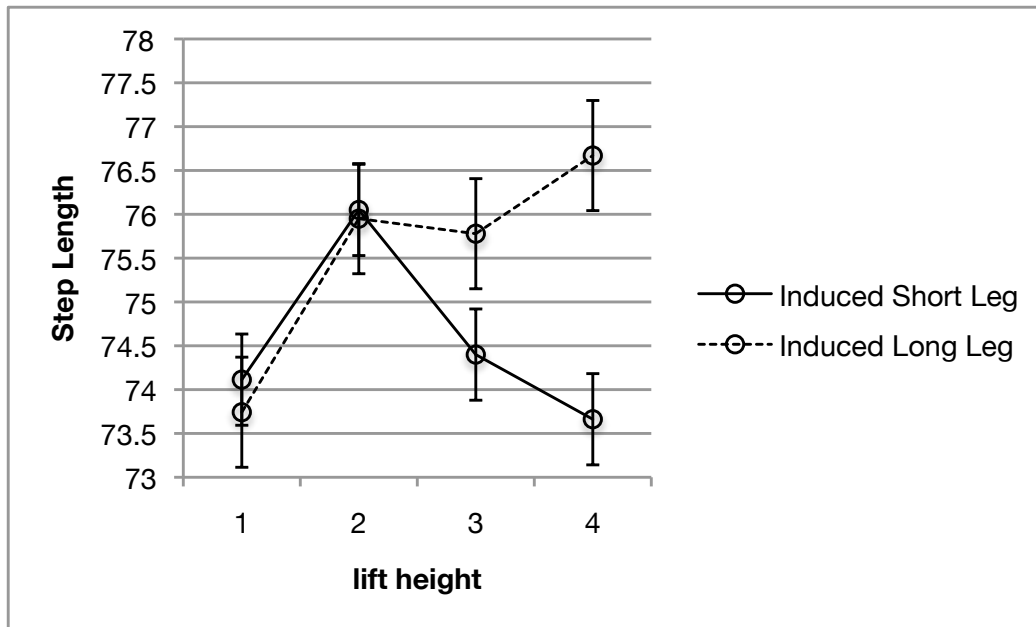
Note: Lift height: 1: *No lift*; 2: *5mm*; 3: *20mm*, 4: *30mm*

Figure 2.6. Toeing (in centimetres), as a function of lift height, separated by side (short versus long leg)
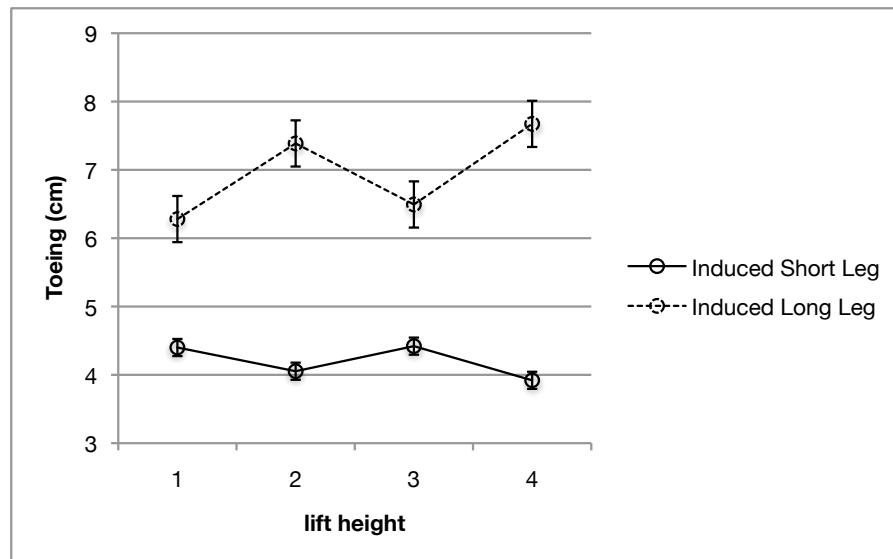
Note: Lift height: 1: *No lift*; 2: *5mm*; 3: *20mm*, 4: *30mm*

showing the greater effect size. The induced long leg had greater overall

amounts of out toeing. Furthermore, patterns were completely opposite for

each leg - as the longer leg out-toed, the shorter leg in-toed.

The results of this study suggest that induced leg length discrepancies of

5mm produce the largest disruptions in temporal-spatial patterns of gait. The

aforementioned findings could be explained by proposing that individuals

compensate for perceived levels of leg length discrepancy, and that these

compensatory strategies are reflected in the elemental components of gait (i.e.,

the temporal-spatial parameters of gait examined within this study).

Accordingly, we would posit a "leg length discrepancy accommodation model"

in which larger discrepancies are more easily detected by the individual, and are

therefore more easily accommodated through an alteration of gross motor

patterns (such as flexing a knee more, or dropping a hip). Evidence of theses

changes in gross motor patterns can be found in previous kinematic research

(Kakushima, Miyamoto, & Shimizu, 2003; Walsh, Connolly, Jenkinson, & O'Brien,

2000). Smaller disruptions in one's leg length may be more difficult to regulate

by altering one's gross motor function, as they may not be immediately evident

to the individual. If the discrepancy is not large enough to be overtly detected,

attentional resources are not directed towards compensatory mechanisms.

 These accommodations do not, of course, mean that the individual has

avoided the development of chronic problems through the use of these

accommodation strategies - although these changes in gross motor patterns

may present the individual with a subjective sense of having adapted to the

discrepancy, it has been suggested that said adaptations may lead to earlier onset of osteoarthritis in the spine (Kaufman, Miller, & Sutherland, 1996). It has also been suggested that correction of leg length discrepancy as small as 5mm may produce significant changes in patients' lower back, hip, and sciatic pain (Friberg, 1983).

Furthermore, it is important to note that all patients who have undergone operative procedures such as total hip and knee arthroplasty will come out with some degree of leg-length discrepancy. It has been suggested that surgeons aim for a post-operative leg length discrepancy of no more than 7mm (Herndon, 2003). The results of this study suggest that management of small discrepancies should be considered as part of the rehabilitation process.

It is unclear from this study, however, and is presented as a limitation of the present research, that the discrepancies here are induced. It may be argued that over time, one might learn to adapt to a smaller discrepancy. Further research should be undertaken, therefore, to determine whether or not individuals learn to accommodate smaller leg length discrepancies over time. Obviously, it is impractical to induce leg length discrepancies using the present methods within a longitudinal study, and so it is likely that this extension to the present research would be done through the use of surgical populations.

Furthermore, the leg length discrepancy accommodation model should be evaluated within a paradigm that allows for the manipulation of attentional resources. In other words, this model proposes that accommodation to leg length discrepancy is (at least in part) accomplished through the use of

attentional resources. A stronger test of the present model would be to stress

the attentional resources of participants, to see if the accommodation to leg

length discrepancies begins to break down as attentional resources become

more scarce. For example, if an individual is asked to engage in a competing

secondary task while engaged in the performance of continuous gait, the leg

length discrepancy accommodation model would predict that the effects of leg

length discrepancy would be exacerbated by the amount of attention allocated

to the secondary task. This use of a "dual-task interference" model would,

therefore, provide evidence that may be used to evaluate the model proposed in

this study.

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Chapter 3:

The Effects of Dual Tasking and Artificially Induced Leg Length

Discrepancy on Gait and Balance[1]

3.1 Introduction

Leg length discrepancy is relatively common in the general population (Gurney, 2002). Clinicians commonly test for leg length discrepancy, due to its prevalence, during standard examinations. Leg length discrepancy can prove frustrating to many clinicians, particularly due to lack of consensus surrounding the amount of discrepancy that necessitates treatment.

The current cutoff for clinical significance has been touched on in our past research. Further to this, previous research has suggested that correcting leg length discrepancies as small as 5mm significantly reduced self-reported lower back pain (Friberg, 1983).

In a previous research study (Dombroski & Johnson, under review) we found that, generally speaking, a relatively small leg length discrepancy (5mm) produced a larger effect than either of two larger discrepancies (20mm and 30mm). We proposed that this finding may be explained within a leg length discrepancy accommodation model, in which individuals purposely self-accommodate when they are able to perceive a qualitatively obvious leg length discrepancy. Conversely, when the discrepancy itself is subtle, they make less of an attempt (if any) to accommodate for the leg length discrepancy within their

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[1] A version of this chapter has been submitted for publication: Dombroski, C., Holmes, J.D., & Johnson, A.M. (under review). The effects of dual-tasking and artificially induced leg length discrepancy on gait and balance. *Gait and Posture.*

gait. This suggests that attentional resources may be involved in the modification of gait, to compensate for a leg length discrepancy. It further suggests when these attentional resources are constrained, these compensatory mechanisms will be similarly impaired, thereby producing a greater change in the parameters of gait.

One method for constraining available attentional resources is the dual-task paradigm. In the case of examining the effects of attentional resources on gait, one might ask an individual to perform a secondary task while performing the primary task of walking. If the execution and maintenance of gait is attention demanding, the addition of a secondary demanding task will produce interference when attentional capacity is exceeded. "Dual task interference" can be identified by observing a decline in performance in one or both attention demanding tasks (Woollacott & Shumway-Cook, 2002). In the context of the present investigation, increasing the complexity of the secondary task (thereby increasing its attentional load, and reducing the attentional capacity that is available to the primary gait task) should reduce the ability of an individual to purposely alter his or her gait. Thus, increasing the complexity of a secondary task should increase the effects of leg length discrepancy, if attentional capacity is involved in the application of compensatory mechanisms within the leg length discrepancy accommodation model.

Thus, the present study investigated the extent to which spatial-temporal properties of gait and posture change as a joint effect of artificially induced leg-length discrepancy, and residual attentional capacity (manipulated by increasing

the complexity of a secondary task). Given the previously reported data that supports a leg length discrepancy accommodation model, we expect that there will be a significant interaction between lift height, and task complexity, with more complex secondary tasks producing a greater gait disruption at higher lift heights.

3.2 Methods

3.2.1 Participants

Forty healthy adults between the ages of 18-40 (Male=17, Female=23) were recruited at the University of Western Ontario. Participants were excluded from the study if they had a pre-existing leg length discrepancy (functional, or structural), scoliosis, were severely overweight, or had significant lower limb pathology. While this study was a follow up to previous research, participants were an entirely separate sample.

3.2.2 Instrumentation

Temporal-spatial properties of gait were quantified using a 20 foot GAITRite electronic walkway. The GAITRite system contains 13,824 pressure sensors and uses a proprietary software package to collect gait variables. The gait variables examined in this study were velocity, step length, heel-to-heel base of support, step time, stance time, single limb support, and double limb support. Balance was assessed using an AMTI force platform, with the variable of interest being the length of the centre of pressure pathway.

3.2.3 Procedure

All participants were assessed by a Canadian certified pedorthist (C.D) in order to ensure that they met the inclusion and exclusion criteria for the study, including an assessment for leg-length discrepancy (functional, or structural with a tolerance of 0 LLD). The participant's legs were measured using the tape measure method as described by Beattie (1990). The tape measure method is a method described often in the literature as an alternative way to measure structural leg length discrepancy (Beattie, et al., 1990). This method involves taking a measurement from the individual's anterior superior iliac spine to the medial malleolus, while the individual is supine on a plinth. The tape measure method is subject to errors due to differences in circumference between the lower extremities, and unilateral deviations along the long axis of the leg, such as genu valgum or varum. Beattie et al. (1990) reported intraclass correlation coefficients of 0.68 for both groups when only one measurement was taken. When the means of two measurements were compared however, this association increased to 0.79, suggesting that the tape measure method demonstrates acceptable concurrent validity. Although the current gold standard of leg length measurement is the scanogram, the mean of two measurements sufficed to objectively alert the examiner to the existence of a leg length discrepancy.

To artificially induce leg length discrepancy, a Pedors post-surgical shoe was modified with 65 shore A durometer ethel vinyl acetate added to the midsole of the shoe to create three different discrepancies (5mm, 20mm, and

30mm), using currently accepted pedorthic procedures described by Janisse (2008).

All participants completed the walking trials on a computerized data-collecting and pressure-sensitive surface (GAITRite®, CIR Systems, Inc., Clifton, NJ, USA) within a large, clutter-free laboratory. Participants were placed in the baseline shoes (no lift) and were instructed to walk clock-wise around the GAITRite carpet at a self selected pace, for three complete circuits, to acclimatize to the new shoe. Leg-length discrepancy was manipulated using the four different shoes described above (i.e., with lifts of 0mm, 5mm, 20mm, and 30mm), with the participant's right foot always receiving the lifted shoe.

In addition to the manipulation of the leg-length discrepancy factor, dual-task interference was manipulated in four blocks (no interference, holding a phone without looking at it, holding a phone and looking at it, and holding a phone while looking at it and dialing). The same cell phone was provided to all participants at the outset of the experiment. Participants did not actually dial phone numbers (as this would tax memory), but rather were asked to cycle through the numbers one through nine as many times as possible during their walk along the carpet, or during their balance trial. To ensure that the numbers were dialed accurately, they were checked at the conclusion of each trial.

The experiment thus involved sixteen blocks: four leg-length discrepancies (0mm, 5mm, 20mm, and 30mm) and four dual-task interference blocks. Three trials were collected within each experimental block, and these blocks were randomized within the walking and balance trials. Twenty

participants completed the walking trials (on the GAITRite) first, and twenty

participants completed the balance trials first. All participants were assessed for

their gait and their balance.

Within the gait trials, participants were asked to walk at a self-selected

pace along the GAITRite carpet, looking straight ahead (except when carrying

out secondary tasks that necessitated looking at the cellular phone). No

instructions were given to participants during the performance of the gait trials,

and participants were instructed not to talk during the task.

For the balance trials, a fresh transparency template was placed over the

force platform for the first balance trial of each participant, with the total force

platform area divided into two equal halves. Participants were asked to stand

comfortably on the force platform with one foot in each half of the force plate.

After they had finished positioning their feet, their foot placement was traced

onto the transparency. This allowed for reproducibility between blocks, within

each participant. The participants were asked to stand comfortably within the

foot template, to place their arms in a comfortable position and to look straight

ahead at a line fixed on the wall (except when carrying out secondary tasks that

necessitated looking at the cellular phone). One of the researchers verified the

absence of knee flexion. Each of the three trials were collected at 60 Hz for ten

seconds.

3.2.4 Statistical Analysis

Gait velocity, and length of the centre-of-pressure pathway, were

analyzed using separate 4x4 analysis of variance (ANOVA) calculations, using

task (no interference, holding a phone without looking at it, holding a phone and looking at it, and holding a phone while looking at it and dialing) and lift (0mm, 5mm, 20mm, and 30mm) as within-subject factors. Post-hoc testing of significant effects within these ANOVAs was done using repeated contrasts (i.e., each mean was compared with adjacent means, to determine whether or not incremental effects were seen for lift height and task complexity). All other dependent variables were analyzed within a 4x4x2 multivariate analysis of variance using task (no interference, holding a phone without looking at it, holding a phone and looking at it, and holding a phone while looking at it and dialing), lift (0mm, 5mm, 20mm, 30mm), and side (left versus right) as within-subject factors. SIgnificant three-way interactions were parsed by examining separate 4x4 MANOVAs evaluating the effects of lift and task for the induced short and long sides. Post-hoc testing of significant effects within these analyses (including, where appropriate, tests of simple main effects) was accomplished using polynomial contrasts within each of the factors.

3.3 Results

All descriptives for the dependent variables are presented in Tables 3.1 through 3.4. For all trials in gait and posture, none of the cellular phone numbers were dialed incorrectly. For velocity, the interaction between lift and task was not statistically significant, nor was the main effect of lift. The effect of task on gait velocity was, however, shown to be statistically significant [F $(3,77.507) = 176.479$, $p<.001$, $\eta^2_{partial}=.819$]. Post hoc testing (using repeated contrasts) revealed statistically significant differences between the "holding" and

Table 3.1. Means (and standard deviations), separated by task and lift, across temporal gait parameters for the left limb (induced short side)

	Step Time (s)				Double Limb Support (s)				Single Limb Support (s)				Stance Time (s)			
	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm
Baseline	.522 (.041)	.526 (.036)	.533 (.042)	.542 (.042)	.230 (.034)	.229 (.035)	.231 (.036)	.227 (.035)	.408 (.025)	.405 (.024)	.405 (.025)	.405 (.023)	.637 (.023)	.633 (.050)	.635 (.053)	.631 (.051)
DT1	.519 (.367)	.523 (.039)	.534 (.041)	.543 (.042)	.230 (.033)	.229 (.035)	.230 (.036)	.246 (.013)	.406 (.026)	.404 (.025)	.405 (.024)	.405 (.025)	.635 (.050)	.633 (.052)	.635 (.052)	.632 (.048)
DT2	.517 (.037)	.523 (.039)	.533 (.041)	.543 (.041)	.232 (.033)	.233 (.034)	.235 (.035)	.230 (.036)	.405 (.025)	.406 (.022)	.402 (.023)	.402 (.022)	.636 (.051)	.637 (.050)	.635 (.053)	.630 (.050)
DT3	.539 (.041)	.537 (.041)	.554 (.045)	.559 (.044)	.258 (.035)	.255 (.036)	.259 (.035)	.251 (.036)	.414 (.027)	.412 (.025)	.408 (.026)	.409 (.025)	.670 (.056)	.665 (.054)	.666 (.054)	.660 (.055)

Notes: Baseline: *no secondary task*; DT1: *holding the phone*; DT2: *holding and looking at the phone*; DT3: *holding, looking at, and dialing the phone*

Table 3.2. Means (and standard deviations) for Velocity and then separated by task and lift, across spatial gait parameters for the left limb (induced short side)

	Velocity (cm/s)				Step Length (cm)				BOS (cm)			
	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm
Baseline	145.775 (17.154)	146.407 (16.545)	145.455 (16.842)	145.018 (17.126)	75.622 (6.120)	76.129 (5.967)	75.204 (6.199)	74.682 (6.255)	9.277 (2.288)	9.080 (2.065)	9.469 (2.633)	9.562 (2.103)
DT1	145.660 (16.143)	147.455 (16.677)	145.200 (16.830)	144.730 (17.793)	74.973 (5.737)	76.010 (5.889)	74.857 (6.296)	74.244 (6.413)	9.456 (2.206)	9.507 (2.342)	9.418 (2.745)	9.862 (2.206)
DT2	143.295 (17.228)	142.895 (15.661)	142.353 (16.534)	141.542 (17.934)	73.617 (6.007)	74.122 (5.594)	73.269 (6.047)	72.414 (6.385)	10.250 (2.235)	9.863 (2.345)	9.865 (2.544)	10.327 (2.570)
DT3	128.685 (16.400)	130.553 (14.870)	128.798 (16.734)	129.747 (18.318)	69.000 (5.919)	69.731 (4.810)	68.758 (5.835)	68.525 (6.279)	10.484 (2.357)	9.709 (2.498)	10.464 (2.372)	10.599 (2.519)

Notes: Baseline: *no secondary task*; DT1: *holding the phone*; DT2: *holding and looking at the phone*; DT3: *holding, looking at, and dialing the phone*

Table 3.3. Means (and standard deviations), separated by task and lift, across temporal gait parameters for the right limb (induced long side)

	Step Time (s)				Double Limb Support (s)				Single Limb Support (s)				Stance Time (s)			
	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm
Baseline	.523 (.037)	.517 (.036)	.516 (.035)	.513 (.032)	.231 (.034)	.229 (.036)	.232 (.036)	.227 (.037)	.408 (.028)	.409 (.026)	.414 (.026)	.423 (.028)	.637 (.055)	.638 (.051)	.643 (.055)	.648 (.054)
DT1	.520 (.347)	.515 (.036)	.515 (.034)	.512 (.032)	.231 (.036)	.230 (.035)	.231 (.035)	.227 (.033)	.406 (.024)	.406 (.026)	.414 (.027)	.424 (.029)	.633 (.049)	.633 (.053)	.642 (.054)	.648 (.052)
DT2	.521 (.036)	.520 (.033)	.513 (.034)	.509 (.031)	.232 (.034)	.232 (.035)	.235 (.036)	.229 (.037)	.403 (.026)	.406 (.026)	.411 (.026)	.422 (.025)	.633 (.051)	.637 (.052)	.643 (.054)	.650 (.053)
DT3	.542 (.040)	.537 (.037)	.531 (.037)	.527 (.038)	.259 (.035)	.255 (.037)	.258 (.035)	.252 (.036)	.410 (.026)	.408 (.027)	.419 (.030)	.427 (.030)	.667 (.055)	.661 (.055)	.677 (.056)	.676 (.057)

Notes: Baseline: *no secondary task*; DT1: *holding the phone*; DT2: *holding and looking at the phone*; DT3: *holding, looking at, and dialing the phone*

Table 3.4. Means (and standard deviations), separated by task and lift, across spatial gait parameters for the right limb (induced long side)

	Velocity (cm/s)				Step Length (cm)				BOS (cm)			
	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm	0mm	5mm	20mm	30mm
Baseline	145.775 (17.154)	146.407 (16.545)	145.455 (16.842)	145.018 (17.126)	75.797 (6.532)	75.808 (5.992)	76.407 (6.567)	77.679 (6.695)	9.409 (2.262)	9.241 (2.096)	9.531 (3.000)	9.566 (2.192)
DT1	145.660 (16.143)	147.455 (16.677)	145.200 (16.830)	144.730 (17.793)	75.657 (6.250)	76.326 (6.055)	76.713 (6.558)	77.752 (6.981)	9.563 (2.133)	9.398 (2.404)	9.438 (2.788)	9.969 (2.148)
DT2	143.295 (17.228)	142.895 (15.661)	142.353 (16.534)	141.542 (17.934)	74.209 (6.606)	74.301 (6.057)	74.932 (6.373)	75.966 (7.124)	10.340 (2.186)	9.956 (2.480)	9.921 (2.708)	10.404 (2.628)
DT3	128.685 (16.400)	130.553 (14.870)	128.798 (16.734)	129.747 (18.318)	69.182 (6.188)	69.621 (5.596)	70.150 (6.598)	71.568 (7.193)	10.543 (2.299)	9.754 (2.499)	10.802 (2.456)	10.645 (2.584)

Notes: Baseline: *no secondary task*; DT1: *holding the phone*; DT2: *holding and looking at the phone*; DT3: *holding, looking at, and dialing the phone*

"holding/looking" tasks and between the "holding/looking" and "holding/looking/dialing" tasks, suggesting that gait velocity slowed as the task became more complex.

Within the MANOVA used to examine the other parameters of gait, a statistically significant interaction was demonstrated between side and lift [F (18,342)=10.84, p<.001], and between side and task [F(18,342)=1.95, p=.012]. The interaction between lift and task was not shown to be significant (p=0.319), but the three way interaction of side, lift, task approached statistical significance at an alpha of .05 (p=.063). Accordingly, this three-way interaction was parsed using simple main effects.

Simple main effects were evaluated through the use of 4x4 MANOVAs conducted for each side individually. These results suggested a significant multivariate effect for the interaction between task and lift on the induced short leg [$F(54, 2106) = 1.359$, $p = .043$, $\eta^2_{partial} = 0.189$], and on the induced long leg [$F(54, 2106) = 1.607$, $p = .004$, $\eta^2_{partial} = 0.219$].

On the induced short side, only step time was significantly predicted by the interaction between lift and task. On the induced long side, only stance time was significantly predicted by the interaction between lift and task. No other dependent variables demonstrated statistically significant univariate effects for this interaction.

Post-hoc testing was done for these significant univariate interactions using a polynomial contrast function for each factor. The best fitting function for

step time in the induced short leg was a linear by quadratic function (i.e., the task was best fit by a quadratic function, within a linear function of lift), [$F_{(1, 39)}$ = 3.901]. This function is depicted graphically in Figure 3.1. Similarly, a linear by quadratic function was shown to be the best fitting function for stance time in the induced long leg [$F_{(1, 39)}$ = 3.775]. This function is depicted graphically in Figure 3.2. These results suggest that, for both of these parameters, the effects of dual task interference (i.e., the gait disruption that occurs as a result of reducing available attentional resources) are greater for larger leg length discrepancies.

The length of the centre-of-pressure pathway was shown to have statistically significant main effects for lift [$F_{(3, 36)}$ = 6.594, $p<.001$, $\eta^2_{partial}$ = 0.335] and task [$F_{(3, 26)}$ = 8.451, $p<.001$, $\eta^2_{partial}$ = 0.413]. The interaction of lift and task was not statistically significant. Post hoc testing was done using simple contrasts for the lift factor, and repeated contrasts for the task factor. A statistically significant difference was found between 30mm and baseline, but no other contrasts were statistically significant. For the main effect of task, although there was a general trend towards having a longer centre-of-pressure pathway, with increases to the complexity of the secondary task, significant effects were demonstrated only for the introduction of the cellphone (i.e., holding the phone, but not looking at it), and for the more complex task of holding and looking at the phone. The dialing task did not significantly increase the length of the centre-of-pressure pathway.

Figure 3.1. Effects of secondary task complexity, separated by lift height, on step time (measured in seconds)
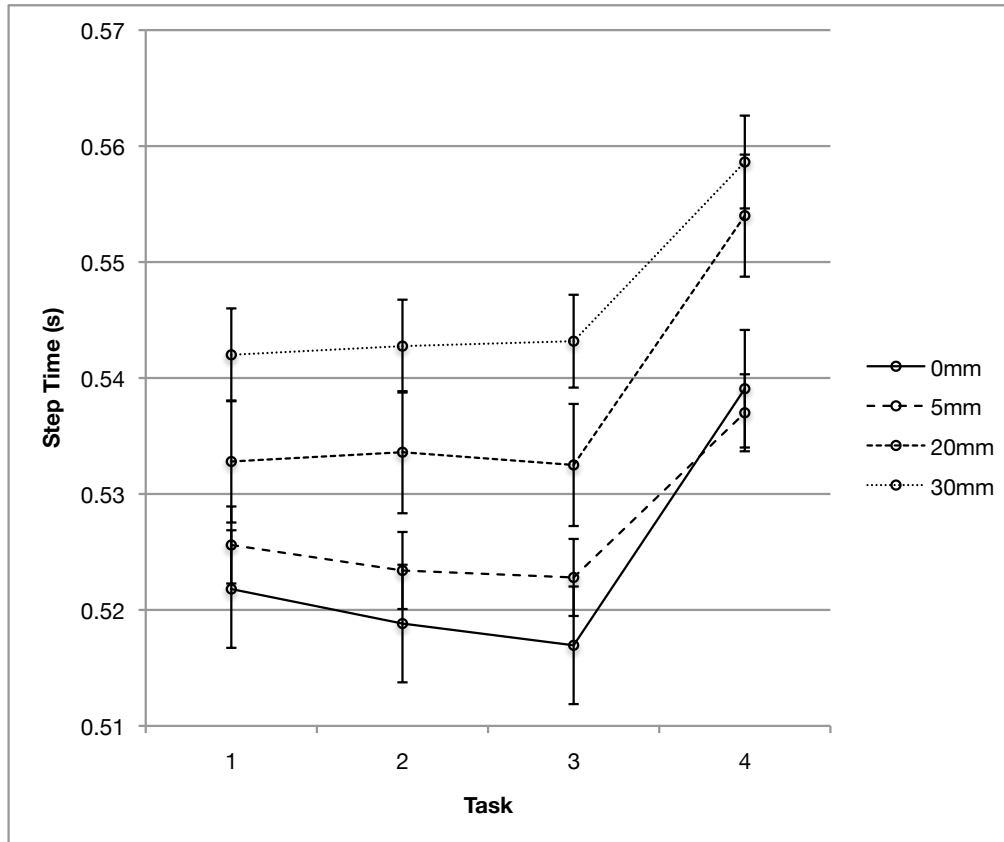
Notes: 1: *no secondary task;* 2: *holding the phone;* 3: *holding and looking at the phone;* 4: *holding, looking at, and dialing the phone*

Figure 3.2. Effects of secondary task complexity, separated by lift height, on stance time (measured in seconds)
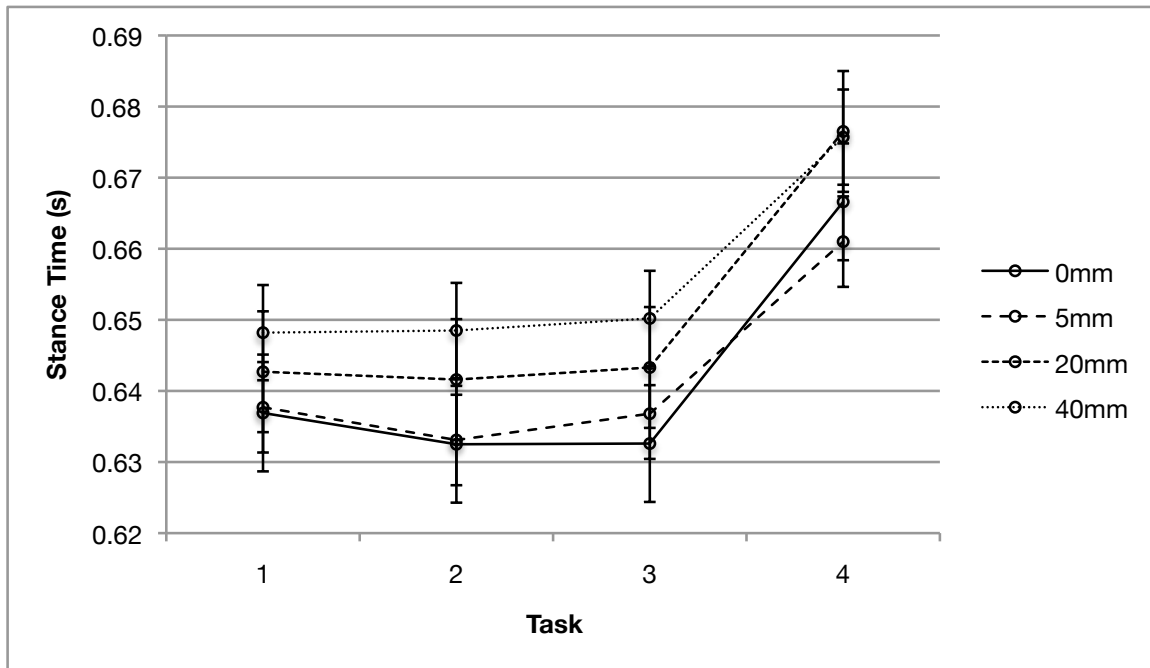
Notes: 1: *no secondary task;* 2: *holding the phone;* 3: *holding and looking at the phone;* 4: *holding, looking at, and dialing the phone*

3.5 Discussion

This study builds upon our previous research that suggested small discrepancies (as little as 5mm) can disrupt temporal/spatial parameters of gait (Dombroski & Johnson, under review). In fact, this previous research suggested that the largest effects are seen with the smallest discrepancies. The theory presented in our previous research is a leg length discrepancy accommodation model, which postulates that people with smaller (5mm) discrepancies are less aware of the fact they have a discrepancy, and, therefore, do not focus sufficient attentional resources required for compensation (thereby enhancing the effects of the discrepancy on the parameters of gait). Missing from this research was a demonstration that a reduction in the availability of attentional resources will produce greater disruption in gait parameters for larger lift heights (with the implication being that individuals are less able to direct efforts at compensating for the effects of leg length discrepancy). We sought to answer this question through the application of a dual-task interference paradigm, in which attentional capacity was manipulated by increasing the complexity of a simultaneously-performed secondary task.

As was the case in our previous research, leg length discrepancy produced significant gait disruption with very small leg length discrepancy manipulations. Interestingly, the manipulation of attentional capacity (through the use of a dual-tasking paradigm) produced a different pattern of results within the lift heights used. Specifically, post hoc analysis of the significant interaction between lift height and task complexity suggested that the effects of leg length

discrepancy at larger lift heights was exacerbated by the complexity of the secondary task. While changes in gait were shown under both 5mm and 30mm discrepancies, effect sizes estimates suggested that on both sides, the addition of the most complex secondary task affected temporal gait parameters the most at 30mm of discrepancy. Placed in the context of our earlier research, it is interesting to note that, at a leg length discrepancy of 30mm, sufficient attention was diverted from gait as to elicit a statistically significant change from baseline.

This provides support for the leg length discrepancy accommodation model. In a situation where a person has a large leg length discrepancy, attention is required to make corrections to one's gait. If attention is diverted due to the introduction of a complex secondary task, one may not be able to accommodate a large discrepancy sufficiently. This decreased ability to focus on gait compensation may magnify the effects of large leg length discrepancy.

With respect to balance, the results suggest that only larger discrepancies disrupt COPL, and that the initial introduction of the secondary task (i.e., holding the phone) produced the greatest change in COPL - possibly a result of the initial destabilizing effect of the motor task. It is interesting to note that although the largest decrease of COPL happened with the simplest task, the effect of complexity lengthened COPL almost back to the original baseline value with the second task of holding while looking at the phone and lengthened it further still with the most complex task (although this task was not shown to be significant). The addition of complexity, past the initial constraint, worked to lengthen COPL.

A limitation presented is that leg length discrepancy was induced, although care was undertaken by the researchers to do so in a valid way. Future research should be undertaken to disentangle the effects of dual tasking on populations with congenital or newly acquired leg length discrepancies. Further, the effects studied here were in a healthy young population, and research has shown that the effects of dual tasking on gait may be exacerbated with age, as age affects one's cognitive ability to complete attention demanding tasks (Oxley, Fildes, Ihsen, Charlton, & Day, 1997).

Given that hip and knee arthroplasty, usually performed on older adults, typically results in some form of leg length discrepancy (Clark, Huddleston, Schoch, & Thomas, 2006), this age group should be studied, as the additional demand of secondary tasks on newly acquired leg length discrepancy may increase the risk of falling. Furthermore, leg length discrepancy in populations with disorders such as Parkinson's disease, where dual tasking has already been shown to affect gait, warrant particular consideration.

The implications of the present research, in the context of our earlier research (Dombroski & Johnson, under review) as it relates to clinical understanding (and practice), is that *larger length discrepancies may require conscious attention for accommodation*. Dual- (and indeed, multi-) tasking is a common feature within the activities of daily living for most individuals. Thus, given the finding that dual task interference exacerbates the potentially deleterious effects of leg length discrepancy on gait, it is unlikely that individuals with naturally occurring leg length discrepancies will be able to consistently

compensate for large leg length discrepancies. When attention is diverted from their gait, potentially pathological gait disturbances may be exhibited, which could lead to an increased risk of injury and fall. This underscores the recommendation from our previous study that surgeons performing operations in which leg length discrepancy is a possible (or even likely) outcome, may want to assess discrepancy post-operatively, in order to provide the patient with information that might be used to deal with perturbations to gait, in a proactive fashion.   While discrepancies are often a reality to patients after surgeries that will increase their quality of life, and decease pain, these discrepancies do not have to be disruptive to gait with proper and judicious follow-up and referral. Full foot lifts are a simple solution to leg length discrepancy, and future research should systematically study the effects of these orthotic devices on gait.

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Chapter 4:

Compensatory Strategies in Patients With Leg Length Discrepancy:

A Study of Post-Surgical Leg Length Discrepancies Among Individuals Who

Have Undergone High Tibial Osteotomy[1]

4.1 Introduction

Leg length discrepancy is common in patients who have undergone joint

arthroplasty or osteotomy (Clark, Huddleston, Schoch, & Thomas, 2006). Due to

the prevalence of post operative leg length discrepancy, clinicians commonly

test for leg length discrepancy during standard musculoskeletal assessments.

Leg length discrepancy can prove frustrating to patients and clinicians alike,

particularly due to lack of consensus surrounding the amount of discrepancy

that necessitates treatment (Clark, et al., 2006).

The current cutoff for clinical significance (i.e., the point at which

treatment is warranted) is a heated topic. Even though it is reasonable to

assume that neuromuscular control and foot loading patterns are affected by leg

length discrepancy (Perttunen, Anttila, Sodergard, Merikanto, & Komi, 2004),

some authors have been bold enough to suggest that leg length discrepancy

does not matter (White & Dougall, 2002). Others have concluded that smaller

leg length discrepancy (3mm), combined with the compounded ground reaction

forces associated with running, may require treatment (Blake & Ferguson, 1992).

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[1] A version of this chapter will be submitted to Gait and Posture: Dombroski C, Johnson AM, Jones I, Giffin R, and Birmingham T. Compensatory Strategies in Patients With Leg Length Discrepancy:
A Study of Post-Surgical Leg Length Discrepancies Among Individuals Who Have Undergone High Tibial Osteotomy. *Gait and Posture*

Furthermore, research has suggested that correction of leg length discrepancies as small as 5mm significantly reduced self-reported lower back pain (Friberg, 1983).

In our previous research, we have demonstrated that induced leg length discrepancy produces significant effects on a variety of gait parameters. We have demonstrated that leg length discrepancies as small as 5mm can produce statistically significant gait change (Dombroski & Johnson, under review), and that smaller leg length discrepancies may, in fact, produce larger amounts of gait change. We have also demonstrated that the effect of leg length discrepancy is (at least in part) a function of the attentional resources that may be brought to bear on compensating for differences in leg length (Dombroski, Holmes, & Johnson, under review). In both of these studies, however, the leg length discrepancies in question were directly manipulated by the investigators, and were not permanent. It is conceivable, therefore, that these findings would not translate into more ecologically valid circumstances outside the lab. The results might, for example, be due to the unfamiliarity of the footwear used to manipulate participant discrepancies. Furthermore, given that we posit that the observed changes in gait parameters are the result of a lack of compensatory mechanisms for subtle leg length discrepancies, it is entirely possible that, given a sufficient amount of time, individuals may learn to accommodate even the smallest leg length discrepancy.

Accordingly, this research may be extended through the use of more "permanent" leg length discrepancies. It is ethically feasible to evaluate two

groups of individuals with leg length discrepancies: (1) individuals who have "naturally occurring" leg length discrepancies; and (2) individuals who have undergone surgical procedures (e.g., high tibial osteotomy) that tend to produce leg length discrepancies. Of these two groups of potential participants, the latter is methodologically preferable, as it is possible to identify a particular (and consistent) time period over which these individuals have had to accommodate a leg length discrepancy, thereby removing this potential confound from the analysis.

The present study investigated the alterations in spatial-temporal parameters of gait (i.e., stride length, step length, stance time, single limb support, step width) seen at one year post-surgery, following a high-tibial osteotomy. The exact magnitude of leg length discrepancy was determined through measurements conducted on x-rays collected pre- and post-surgery, and temporal-spatial parameters of gait were collected using 3D motion capture systems, both before and after the leg-length discrepancy was induced through the surgical procedure. This methodology allows for the evaluation of changes to gait that are a function of the leg length discrepancy, through the use of an analysis of covariance (in which induced leg length discrepancy was the covariate). Given our previous research findings, we hypothesize that leg length discrepancy will have a statistically significant effect on the change in gait parameters.

4.2 Methods

4.2.1 Participants

The data for this study comes from a larger data set of consecutively sampled participants who underwent high tibial osteotomy surgery within the clinical practices of orthopaedic surgeons in the Fowler-Kennedy Sport Medicine Clinic. All individuals (n=93) who had x-rays performed before and after the surgical procedure were extracted from the larger dataset, for analysis within the present study.

4.2.2 Instrumentation

Temporal-spatial properties of gait were quantified using an 8-camera motion capture system (Eagle EvaRT; Motion Analysis Corporation, Santa Rosa, CA) synchronized with a floor mounted force platform (Advanced Mechanical Technology, Watertown, MA), using a proprietary software package to collect gait variables. The gait variables examined were: step length, stride length, step width, stance time, and single limb support time (measured as a percentage of the gait cycle). A modified Helen Hayes 22 passive-reflective marker set was utilized.

4.2.3 Procedure

Participants walked barefoot within a large, clutter-free laboratory, while 3-dimensional kinetic (sampled at 1,200 Hz) and kinematic (sampled at 60 Hz) data were recorded in the middle of several strides during at least 5 trials from each extremity. Leg length was measured by taking the sum of the femoral mechanical axis (centre of hip to centre of knee) and tibial mechanical axis

(centre of knee to centre of ankle) for both limbs, and discrepancy was measured by subtracting the unaffected limb from the affected limb, post surgery.

4.3 Statistical Analysis

Changes in gait parameters were analyzed in SPSS utilizing a repeated measures, multivariate analysis of covariance (MANCOVA), using side (affected versus unaffected) and time (pre-surgery versus post-surgery) as within-subject variables, and the magnitude of leg length discrepancy post-surgery as a covariate. This method was used to estimate the impact of leg-length discrepancy on the temporal-spatial parameters of gait. "Noise" generated by the leg length discrepancy was interpreted as the difference of partial eta squares between the pre- and post-time periods.

4.4 Results

All descriptives for the dependent variables are presented in Table 4.1. Within the MANCOVA used to examine parameters of gait, a statistically significant multivariate interaction was demonstrated between time (pre-surgery versus post-surgery) and side (affected versus unaffected side), $[F(4, 88) = 13.994, p<0.001, \eta^2_{partial} = 0.389]$. Furthermore, statistically significant

multivariate effects were demonstrated for the main effects of time $[F(4, 88) = 9.365, p<0.001, \eta^2_{partial} = 0.299]$ and for side $[F(4, 88) = 5.771, p<0.001, \eta^2_{partial} = 0.208]$. Three of the four dependent variables (step length, stance time, and

Table 4.1. Means (and standard deviations), separated by affected and unaffected limbs, across all gait parameters pre and post-surgery.

	Pre-Surgery		Post-Surgery	
	Affected	Unaffected	Affected	Unaffected
Stance (%)	61.544 (1.604)	62.556 (1.932)	61.046 (2.890)	61.090 (2.850)
Single Limb Support (%)	37.444 (1.932)	38.456 (1.504)	38.910 (2.850)	38.954 (2.890)
Stride Length (cm)	1.293 (0.141)	1.294 (0.142)	1.306 (0.145)	1.306 (0.150)
Step Length (cm)	0.642 (0.072)	0.643 (0.725)	0.655 (0.074)	0.640 (0.075)

Note: stance time and single limb support time are presented as percentages of the gait cycle.

single limb support time) proved statistically significant under univariate analysis of the interaction of time and side.

Interestingly, when leg length discrepancy was added as a covariate (the average covariate in the model was estimated to be 3.4mm of discrepancy), the multivariate effect for the interaction of time and side was rendered statistically non-significant (p = 0.973, $\eta^2_{partial}$ = 0.006) as was the main effect of time (p = 0.743). The main effect for side was, however, still statistically significant after controlling for leg length discrepancy, [$F(4, 88)$ = 4.025, p = 0.005, $\eta^2_{partial}$ = 0.155]. This would suggest that 38.3% of the variability in the temporal-spatial changes post surgery were attributed to leg length discrepancy. These significant interactions are graphically displayed in Figures 4.1 through 4.3.

4.5 Discussion

This research shows that although temporal-spatial gait parameters did change post-surgery, when the interference created by the acquired leg length discrepancy was removed, these changes were no longer statistically significant. This suggests that the most important factor in the prediction of post-surgical spatial-temporal parameters of gait, is leg length discrepancy. While it is reasonable to assume that changes in gait would be present after a high-tibial osteotomy, and that influences on gait would be multi-factorial in nature, the results of this analysis suggest that 38.3% of the variability in the temporal spatial changes post surgery are attributable to leg length discrepancy. Future

Figure 4.1. Stance time (measured as a percentage of the gait cycle), as a function of time (pre- versus post-surgery), separated by side (affected versus unaffected).
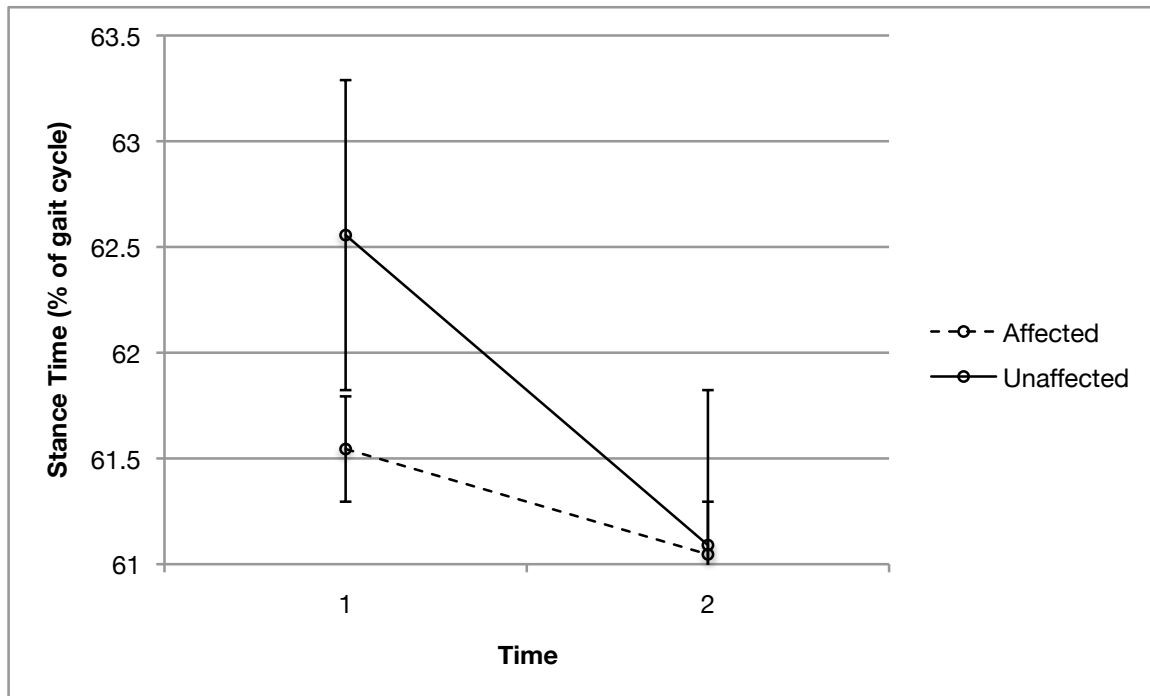
Note: Time: 1: *Pre-surgery;* 2: *Post-surgery*

Figure 4.2. Single limb support (measured as a percentage of the gait cycle), as a function of time (pre- versus post-surgery), separated by side (affected versus unaffected).
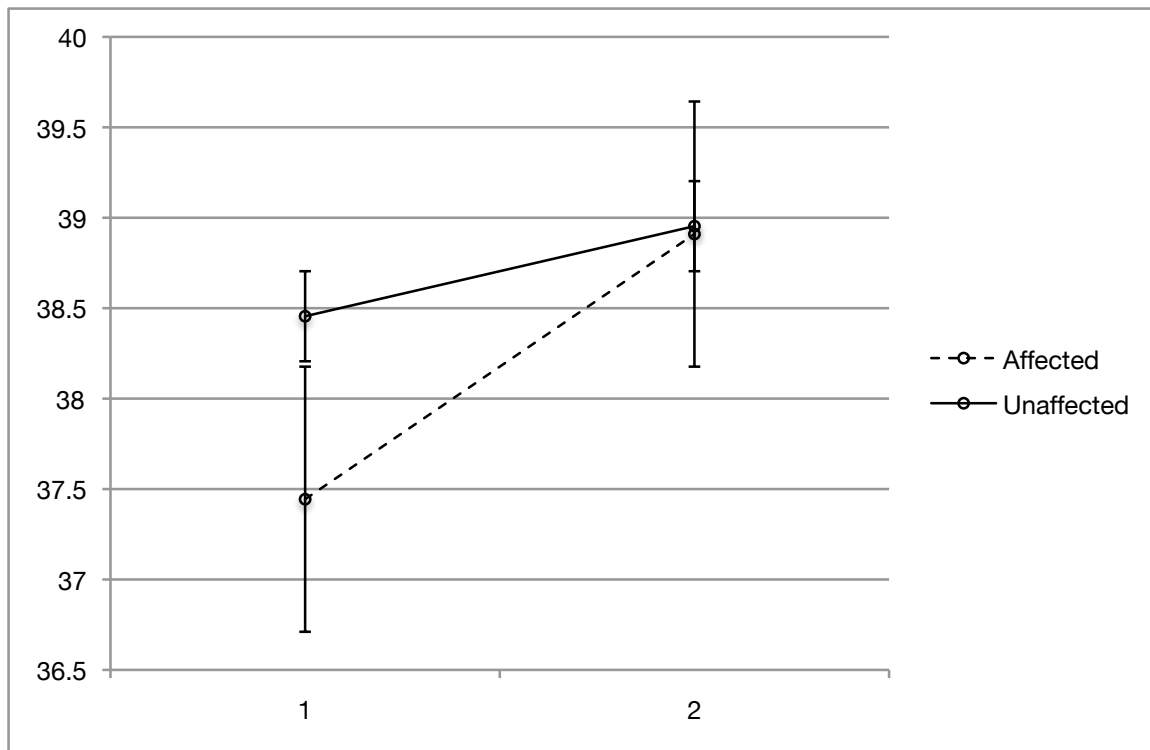
Note: Time: 1: *Pre-surgery;* 2: *Post-surgery*

Figure 4.3. Step length (measured in centimetres), as a function of time (pre-versus post-surgery), separated by side (affected versus unaffected).
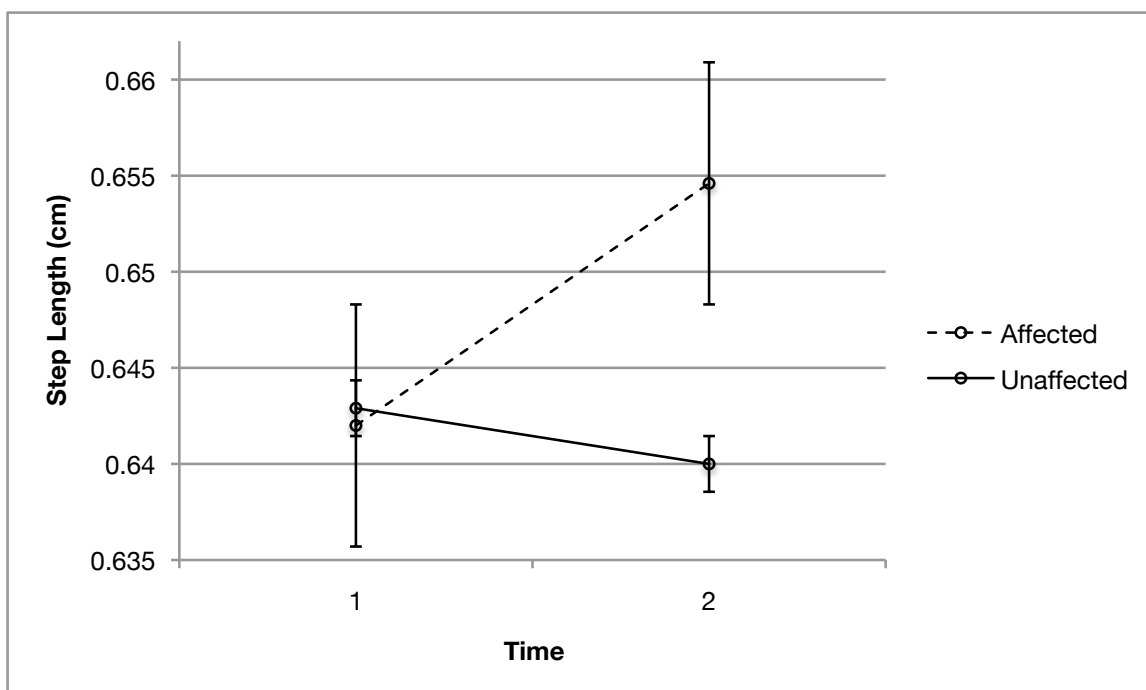
Covariates appearing in this model are evaluated at the following values: LLD= 3.4269

Note: Time: 1: *Pre-surgery;* 2: *Post-surgery*

research should endeavor to disentangle the other possible confounding variables, such as pain; stiffness etc.

A key limitation to our previous research (Dombroski, Holmes, & Johnson, under review; Dombroski & Johnson, under review) was that leg length discrepancy was induced. This raised the question of whether an individual would learn to adapt to this discrepancy over time. The present study not only showed that leg length discrepancy affected gait 12 months post surgery but also that the magnitude of discrepancy was enough to elicit change. These results are in line with one body of research suggesting that leg length discrepancy as small as 3-5mm can produce changes in ground reaction forces and can change ratings of pain (Blake & Ferguson, 1992; Friberg, 1983), while contradicting another body research suggesting that leg length "does not matter" (White & Dougall, 2002).

Leg lengthening through surgery can have advantages in areas such as knee adduction moment, whereby the by-product of the lengthening is greater foot pronation, and thus a smaller knee adduction moment. As knee adduction moment is used as a proxy for knee joint loading, decreasing adduction moment through leg lengthening could be viewed positively. Conversely, the same lengthening can have negative effects on musculature, such as increased demand on tibialis posterior, soleus, and flexor digitorum longus to control the effects of increased foot pronation. This increased utilization of lower limb musculature could potentially lead to overuse in athletic and sedentary populations alike.

Future research should endeavor to study the effects of post-surgical intervention through referral to a Certified Pedorthist for lift intervention to see if temporal spatial gait changes are controlled for clinically with the use of shoe lifts, and/or custom made foot orthoses.

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Chapter 5

General Discussion

In an aging population, it is generally accepted that the overall prevalence of osteoarthritis is going to rise. Given that the intervention for end stage, pain inducing, bone on bone arthritis is joint arthroplasty surgery, and that the post-surgical reality of these surgeries includes some form of leg length discrepancy (Clark, Huddleston, Schoch, & Thomas, 2006), a better understanding of leg length discrepancy is necessary for adequate clinical treatment and follow-up.

The leg length discrepancy literature is typified by a general lack of agreement as to the point at which treatment is warranted. Blake et al. (1992) reported that a leg length discrepancy of only 3mm can be clinically relevant to runners due to the increase in ground reactive forces upon heel strike, and Friberg (1983) reported that a 5mm leg length discrepancy is enough to be a contributing factor in the development of low back pain. Conversely, White et al. (2002) reported, however, that a leg length discrepancy of up to 19mm was acceptable.

Structural leg length discrepancy, and the alterations in biomechanical function that is associated with it, is thought to be a contributing factor to many clinical pathologies (Etnier & Landers, 1998; Friberg, 1983; Giles & Taylor, 1981; Gurney, 2002; Hanada, Kirby, Mitchell, & Swuste, 2001; Kakushima, Miyamoto, & Shimizu, 2003; Walsh, Connolly, Jenkinson, & O'Brien, 2000). These pathologies include lower back pain, osteoarthritis of the hip, aseptic loosening of hip prostheses, lower limb stress fractures, knee pain, and poor running

economy. Many authors have linked leg length discrepancies to these pathologies by way of the compensatory mechanisms developed by the patient (Friberg, 1983; Giles & Taylor, 1981; Kakushima, et al., 2003; Kaufman, Miller, & Sutherland, 1996; Papaioannou, Stokes, & Kenwright, 1982). This dissertation was designed around an examination of compensatory mechanisms, with the over-riding goal being an increased understanding of the circumstances under which one begins to modulate gait, in an effort to accommodate a leg length discrepancy.

The first study demonstrated that induced leg length discrepancies of 5mm produce the largest disruptions in temporal-spatial patterns of gait between legs. This finding was explained by proposing that individuals compensate for *perceived* levels of leg length discrepancy (i.e., levels of leg length discrepancy that are qualitatively obvious to the individual), and that these compensatory strategies are reflected in the elemental components of gait (i.e., the temporal-spatial parameters of gait measured by the GAITRite). To this end, we proposed a "leg length discrepancy accommodation model" (see figure 5.1) in which larger discrepancies are more easily detected by the individual, and are therefore more easily accommodated through an alteration of gross motor patterns (such as flexing a knee more, or dropping a hip).   Smaller disruptions in one's leg length may be more difficult to regulate by altering one's gross motor function, as they may not be immediately evident to the individual. If the discrepancy is not large enough to be overtly detected, attentional resources are not directed towards compensatory mechanisms.

These accommodations do not, of course, mean that the individual has avoided the development of chronic problems through the use of these accommodation strategies. Although these changes in gross motor patterns may present the individual with a subjective sense of having adapted to the discrepancy, it has been suggested that said adaptations may lead to earlier onset of osteoarthritis in the spine (Kaufman, et al., 1996). It has also been shown that correction of leg length discrepancies as small as 5mm can produce significant changes in patients' lower back, hip and sciatic pain (Friberg, 1983).

As stated by Gurney (2002), leg length discrepancy that is acquired later in life, as the result of trauma or surgery, seems to be the more debilitating of the two. This finding may have a multi-factorial explanation, relating to age, and our proposed leg length discrepancy accommodation model. If age affects one's cognitive ability to complete attention-demanding tasks (Oxley, Fildes, Ihsen, Charlton, & Day, 1997) and if attentional resources may be involved in the modification of gait, to compensate for a leg length discrepancy (Dombroski & Johnson, under review), it is suggested by study two of this thesis that when these attentional resources are constrained, that these compensatory mechanisms will be similarly impaired, thereby producing a greater change gait (and a corresponding change in the measured parameters of gait). The aim of study two, therefore, was to further elucidate our leg length discrepancy accommodation model by showing that accommodation to leg length discrepancy is (at least in part) mediated by the availability of attentional resources.

Study two corroborated our earlier findings, demonstrating that leg length discrepancy can produce significant gait disruption with very small leg length discrepancy manipulations. Interestingly, the manipulation of attentional capacity (through the use of a dual-tasking paradigm) produced a different pattern of results within the lift heights used. Specifically, post hoc analysis of the significant interaction between lift height and task complexity suggested that the effects of leg length discrepancy at larger lift heights was exacerbated by the complexity of the secondary task. While changes in gait were shown under both 5mm and 30mm discrepancies, effect sizes estimates suggested that on both sides, the addition of the most complex secondary task affected temporal gait parameters the most at 30mm of discrepancy. Placed in the context of our earlier research, it is interesting to note that, at a leg length discrepancy of 30mm, sufficient attention was diverted from gait as to elicit a statistically significant change from baseline.

The findings of study two provide complementary support for our leg length discrepancy accommodation model (see figure 5.1), through a demonstration of statistically significant attention effects in larger discrepancies. In a situation where a person has a large leg length discrepancy, attention is required to make corrections to one's gait. If attention is diverted, due to the introduction of a complex secondary task, one may not be able to accommodate a large discrepancy sufficiently. This decreased ability to focus on gait compensation may magnify the effects of large leg length discrepancy. The implications of this research as it relates to clinical understanding (and

Figure 5.1 The Leg Length Discrepancy Model (LLDAM)
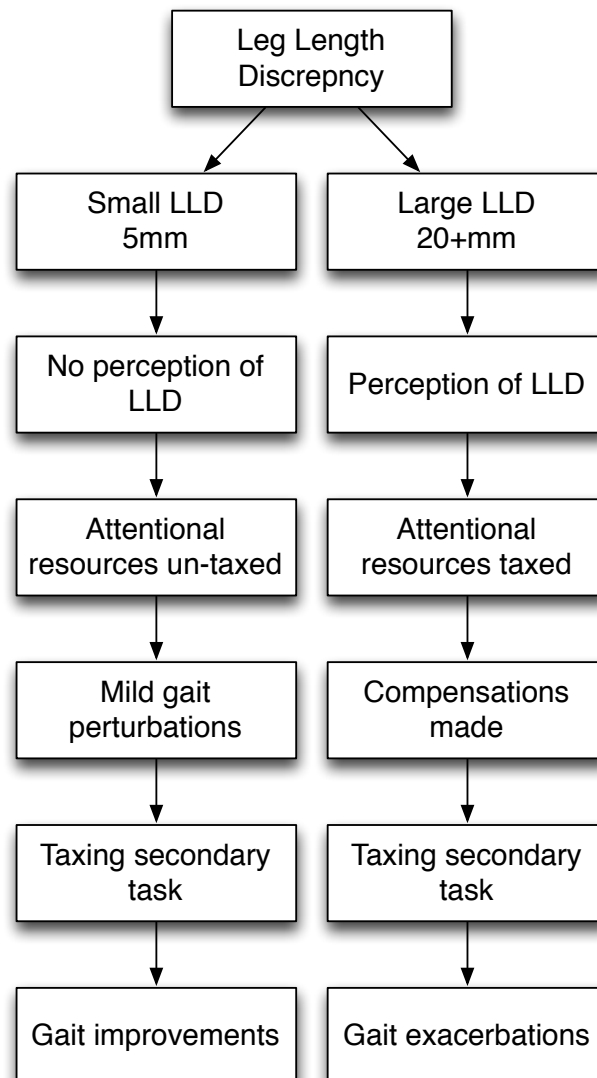
```
                        ┌─────────────────┐
                        │   Leg Length    │
                        │   Discrepncy    │
                        └─────────────────┘
                           ↙          ↘
            ┌─────────────────┐   ┌─────────────────┐
            │   Small LLD     │   │   Large LLD     │
            │     5mm         │   │    20+mm        │
            └─────────────────┘   └─────────────────┘
                     ↓                     ↓
            ┌─────────────────┐   ┌─────────────────┐
            │ No perception of│   │ Perception of LLD│
            │      LLD        │   │                 │
            └─────────────────┘   └─────────────────┘
                     ↓                     ↓
            ┌─────────────────┐   ┌─────────────────┐
            │   Attentional   │   │   Attentional   │
            │ resources un-taxed│ │ resources taxed │
            └─────────────────┘   └─────────────────┘
                     ↓                     ↓
            ┌─────────────────┐   ┌─────────────────┐
            │   Mild gait     │   │  Compensations  │
            │  perturbations  │   │      made       │
            └─────────────────┘   └─────────────────┘
                     ↓                     ↓
            ┌─────────────────┐   ┌─────────────────┐
            │ Taxing secondary│   │ Taxing secondary│
            │      task       │   │      task       │
            └─────────────────┘   └─────────────────┘
                     ↓                     ↓
            ┌─────────────────┐   ┌─────────────────┐
            │Gait improvements│   │Gait exacerbations│
            └─────────────────┘   └─────────────────┘
```

practice), is that larger length discrepancies may require conscious attention for accommodation. Dual (and indeed, multi) tasking is a common feature within the activities of daily living for most individuals. Thus, with the finding that dual task interference exacerbates the potentially deleterious effects of leg length discrepancy on gait, it is unlikely that individuals with naturally occurring leg length discrepancies will be able to consistently compensate for large leg length discrepancies. When attention is diverted from their gait, potentially pathological gait disturbances may be exhibited, which could lead to an increased risk of injury and fall.

In both studies one and two, however, the leg length discrepancies in question were directly manipulated by the investigators, and were not "permanent leg length discrepancies." It was conceivable, therefore, that these findings would not translate into more ecologically valid circumstances outside the lab. The results might, for example, have been due to the unfamiliarity of the footwear used to manipulate participant discrepancies. Furthermore, given that we posited that the observed changes in gait parameters were the result of a lack of compensatory mechanisms for subtle leg length discrepancies, it was entirely possible that, given a sufficient amount of time, individuals may learn to accommodate even the smallest leg length discrepancy. In study three, we set out to examine temporal-spatial variables of gait in a population with newly surgically acquired leg length discrepancy.

The results of study three demonstrated that although temporal-spatial gait parameters did change post-surgery, when the interference created by the

acquired leg length discrepancy was removed, these changes were no longer statistically significant. This suggests that the most important factor in the prediction of post-surgical spatial-temporal parameters of gait, is leg length discrepancy. While it is reasonable to assume that changes in gait would be present after a high-tibial osteotomy, and that influences on gait would be multi-factorial in nature, the results of this analysis suggest that 38.3% of the variability in the temporal spatial changes post surgery are attributable to leg length discrepancy. Furthermore, these results not only showed that leg length discrepancy affected gait 12 months post surgery but also that the magnitude of discrepancy (3.4mm, on average) was enough to elicit change. These results are in line with one body of research suggesting that leg length discrepancy as small as 3-5mm can produce changes in ground reaction forces and can change ratings of pain (Blake & Ferguson, 1992; Friberg, 1983), while contradicting another body research suggesting that leg length "does not matter" (White & Dougall, 2002).

Taken together, the results of these three studies provide several important pieces of clinical information: (1) small discrepancies (as small as 5mm) can disrupt gait; (2) larger discrepancies (particularly when they are qualitatively obvious to the individual) may require conscious attention to the gait adaptation; (3) conscious gait adaptation may be be disrupted by attention-demanding secondary tasks; and (4) the effects of acquired leg-length discrepancy persist for as long as a year after they are induced.

5.1 Limitations of the Present Studies and Future Directions

Leg lengthening through surgery can have advantages in areas such as knee adduction moment, whereby the by-product of the lengthening is greater foot pronation, and thus a smaller knee adduction moment. As knee adduction moment is used as a proxy for knee joint loading, decreasing adduction moment through leg lengthening could be viewed positively. Conversely, the same lengthening can have negative effects on musculature, such as increased demand on tibialis posterior, soleus, and flexor digitorum longus to control the effects of increased foot pronation. This increased utilization of lower limb musculature could potentially lead to overuse in athletic and sedentary populations alike. Although this research program cannot (at present) identify which outcome is more than the other, it is inarguable that a change exists that can be largely explained through a control of leg length discrepancy. Future directions in this area should endeavour to disentangle the kinetic effects of leg length discrepancy, and should do so under attention-demanding loads.

An additional limitation to the research presented in chapter three is that the effects studied were in a healthy young population. Research has shown that the effects of dual tasking on gait may be exacerbated with age, as age affects one's cognitive ability to complete attention demanding tasks (Oxley, et al., 1997). Given that hip and knee arthroplasty, usually performed on older adults, typically results in some form of leg length discrepancy (Clark, et al., 2006), this age group should be studied, as the additional demand of secondary tasks on newly acquired leg length discrepancy may increase the risk of falling.

Furthermore, leg length discrepancy in populations with disorders such as Parkinson's disease, where dual tasking has already been shown to affect gait , warrant particular consideration. Given that the effects of dual-task interference are likely to be greater within an older population, however, it is likely that the results presented within this dissertation are conservative.

Future research should also endeavour to study the effects of post-surgical intervention through referral to a Certified Pedorthist for lift intervention to see if temporal-spatial gait changes are controlled for clinically with the use of shoe lifts, and/or custom made foot orthoses. While discrepancies are often a reality to patients after surgeries that will increase their quality of life, and decease pain, these discrepancies do not have to be disruptive to gait with proper and judicious follow-up and referral. Full foot lifts are a simple solution to leg length discrepancy, and future research should systematically study the effects of these orthotic devices on gait.

5.2 Conclusion

Leg length discrepancy and its accommodations may, in fact, be more complex than some of the literature currently suggests. If gait is a largely automatic process, it would be unaffected by the variables presented in this research. What we can glean, however, is that gait is modifiable by changes in one's leg length, and the changes by the body to accommodate to this discrepancy are affected by attention, when the discrepancy is large. Furthermore, small discrepancies of 3-5mm are enough to produce lasting change in temporal spatial gait variables. While this research is not definitively

suggestive of treatment of these discrepancies, it does suggest, however, that

judicious post-operative attention should be given. Future research should be

undertaken to understand what happens to gait when these discrepancies are

normalized through full foot lift therapy.

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Appendix A

Glossary of Terms

Term	Definition
Foot Pronation	The combination of tri-planar movements that lowers the medial longitudinal arch and orients the plantar surface of the foot away from the midline.
Foot Supination	The combination of tri-planar movements that raises the medial longitudinal arch and orients the plantar surface of the foot towards the midline.
Knee Adduction Moment	Knee adduction moment is the product of the frontal plane ground reaction force (GRF) and the moment arm and is a proxy for knee joint loading.
High-Tibial Osteotomy	A surgery in which the the angle of the tibia is surgically corrected, altering joint loading.
Ankle Equinus Deformity	An ankle that is fixed in planterflexion or when the forefoot is in a fixed position below the midfoot. Can be functional then the superficial posterior musculature of the lower leg is tight.
Temporal Spatial Parameters of Gait	The timing and spacial orientations of the foot as it moves through the gait cycle.

Appendix B

Ethics Certificates

Protocol 13388E (Chapter 2)
Protocol 15459E (Chapter 3)

Office of Research Ethics

The University of Western Ontario
Room 00045 Dental Sciences Building, London, ON, Canada N6A 5C1
Telephone: (519) 661-3036 Fax: (519) 850-2466 Email: ethics@uwo.ca
Website: www.uwo.ca/research/ethics

Western

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson
Review Number: 13388E **Review Level:** Expedited
Review Date: June 20, 2007
Protocol Title: The Effect of Artificially Induced Leg Length Discrepancy on Spatial Temporal Parameters of Gait
Department and Institution: Faculty of Health Sciences, University of Western Ontario
Sponsor:
Ethics Approval Date: July 10, 2007 **Expiry Date:** June 30, 2008
Documents Reviewed and Approved: UWO Protocol, Letter of information and consent
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced study on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:
    a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
    b) all adverse and unexpected experiences or events that are both serious and unexpected;
    c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

Chair of HSREB: Dr. John W. McDonald
Deputy Chair: Susan Hoddinott

Ethics Officer to Contact for Further Information		
☐ Jennifer McEwen (jmcewen4@uwo.ca)	☐ Denise Grafton (dgrafton@uwo.ca)	☐ Ethics Officer (ethics@uwo.ca)

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cc: ORE File
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Office of Research Ethics

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Website: www.uwo.ca/research/ethics

Western

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson		
Review Number: 13388E	**Revision Number:** 1	
Review Date: July 17, 2008	**Review Level:** Expedited	
Protocol Title: The Effect of Artificially Induced Leg Length Discrepancy on Spatial Temporal Parameters of Gait		
Department and Institution: Faculty of Health Sciences, University of Western Ontario		
Sponsor:		
Ethics Approval Date: July 17, 2008	**Expiry Date:** June 30, 2009	
Documents Reviewed and Approved: Revised study end date.		
Documents Received for Information:		

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

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a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.
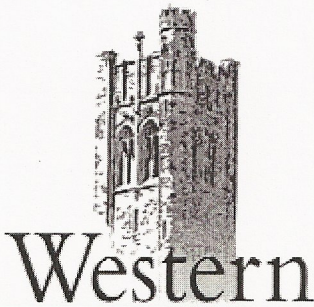
Chair of HSREB: Dr. Paul G. Harding

Ethics Officer to Contact for Further Information			
☐ Janice Sutherland (jsutherl@uwo.ca)	☐ Elizabeth Wambolt (ewambolt@uwo.ca)	☐ Grace Kelly (grace.kelly@uwo.ca)	☐ Denise Grafton (dgrafton@uwo.ca)

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Office of Research Ethics

The University of Western Ontario
Room 4180 Support Services Building, London, ON, Canada N6A 5C1
Telephone: (519) 661-3036 Fax: (519) 850-2466 Email: ethics@uwo.ca
Website: www.uwo.ca/research/ethics

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson

Review Number: 13388E   **Revision Number:** 2

Review Date: July 24, 2009   **Review Level:** Expedited

Protocol Title: The Effect of Artificially Induced Leg Length Discrepancy on Spatial Temporal Parameters of Gait

Department and Institution: Faculty of Health Sciences, University of Western Ontario

Sponsor:

Ethics Approval Date: July 24, 2009   **Expiry Date:** June 30, 2010

Documents Reviewed and Approved: Revised Study End Date

Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.
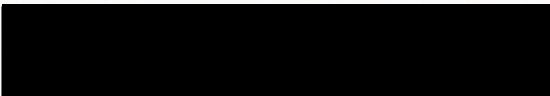
During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
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If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

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Chair of HSREB: Dr. Joseph Gilbert

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LHRI

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Website: www.uwo.ca/research/ethics

Western

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson
Review Number: 15459E **Review Level:** Expedited
Review Date: September 10, 2008
Protocol Title: The Effects of Dual Tasking and Artificially Induced Leg Length Discrepancy on Gait, Posture, and EMG
Department and Institution: Faculty of Health Sciences, University of Western Ontario
Sponsor:
Ethics Approval Date: October 9, 2008 **Expiry Date:** September 30, 2009
Documents Reviewed and Approved: UWO Protocol, Letter of Information and Consent.
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced study on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

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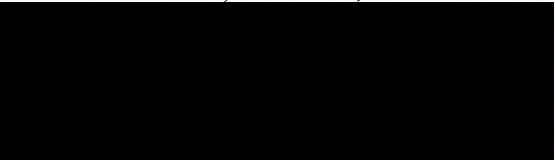
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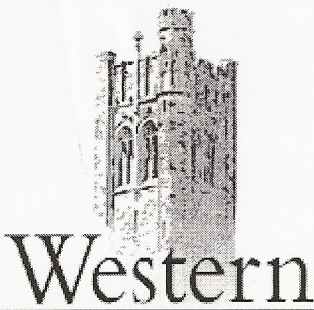
Chair of HSREB: Dr. Joseph Gilbert

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                                                                            LHRI

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Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. A.M. Johnson	
Review Number: 15459E	**Revision Number:** 1
Review Date: July 10, 2009	**Review Level:** Expedited
Protocol Title: The Effects of Dual Tasking and Artificially Induced Leg Length Discrepancy on Gait, Posture, and EMG	
Department and Institution: Faculty of Health Sciences, University of Western Ontario	
Sponsor:	
Ethics Approval Date: July 10, 2009	**Expiry Date:** September 30, 2010
Documents Reviewed and Approved: Revised study end date, study methods and participant recruitment. Letter of Information.	
Documents Received for Information:	

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

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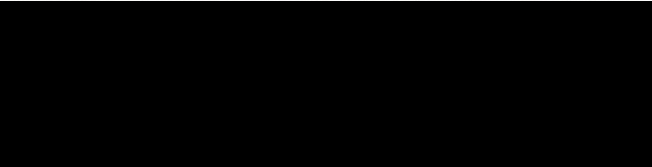
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Curriculum Vitae
Colin Dombroski, BHSc, C Ped C, PhD (C)

Education

University Of Western Ontario

Doctorate in Health and Rehabilitation Science (Candidate), Current

Post-Graduate Certificate Program in Pedorthics, 2002

Bachelor of Health Science (BHSc), 2003

Certifications

Canadian Certified Pedorthist (C Ped C)

Canadian Certified Pedorthic Technician (C Ped Tech C)

Professional Affiliations

The Pedorthic Association Of Canada

The College of Pedorthics of Canada

The Serotta International Cycling Institute

The Prescription Footwear and Orthotic Lab Association

Curriculum and Educational Contributions

Sole Organizer of the Annual SoleScience Foot and Lower Extremity Symposium (2005-Current)

Director of the SoleScience Academy for Professional Education

UWO: Diploma Program in Pedorthics curriculum, Leg Length Discrepancy

Retul University: Leg Length Discrepancies and Cycling

Guest Lectures and Courses Taught

Six Nations Polytechnic- Course Instructor: Personal Determinants of Health, 2011

Six Nations Polytechnic- Course Instructor: Social Determinants of Health, 2011

UWO, Schulich School Of Medicine: Academic half day guest lectures in Foot Assessment, Diagnosis and Treatment. 2005-Current.

UWO Physiotherapy Program: Guest lectures in Functional Anatomy *and* Sport Specific Footwear. 2004-Current.

UWO: Pedorthic Practicum site, Clinical and Lab placements sites.

UWO: Course Instructor of Kinesiology 494b Field Placement in Pedorthics. 2004-2007.

Symposia Lectures

2011- Pedorthic Association of Canada *"The Combined Effects of Custom Made Laterally Wedged Foot Orthoses and Custom Knee Bracing"*

2011- Pedorthic Association of Canada *"Going Green in the Lab, a Case Study"*

2010- North American Pedorthic Congress *"Pedorthic Oriented Bike Fit"*

2008- The Prescription Footwear and Orthotic Lab Association *"Leg Length Discrepancy, Gait and Cycling"*

2008- Pedorthic Association Of Canada National Conference *"Leg Length Discrepancy, the 30mm Dilemma"*

2007- Pedorthic Association of Canada Annual Symposium *"The Effect of Artificially Induced Leg Length Discrepancy on Cycling Kinematics:*

2007- OCHA Annual Conference *"What to expect from a Pedorthic Practice"*

2006- Ontario Medical Association (Sport Med) Conference *"Gait Analysis and Foot Assessment for Physicians"*

2005- Fowler-Kennedy Sport Medicine Homecoming Symposium *"Athletic Footwear, Its All about the Fit"*

2004- Pedorthic Association of Canada, National Conference *"Patella Femoral Pain Syndrome, A Pedorthic Approach"*

2004- Fowler-Kennedy Sport Medicine Homecoming Pre-Symposium Workshop *"Pediatrics and Pedorthics"*

Poster Presentations:

2011- American Society of Biomechanics "*Investigating in-vivo motion of the medial longitudinal arch with different orthotic types using lateral fluoroscopy images during dynamic gait"*

2011- American Society of Biomechanics *"A Comparison of the affect of soft and rigid custom-made corrective orthotics and over-the-counter proprioceptive Feedback orthotics on Hindfoot Pronation During Walking Gait: A Two-Dimensional Dynamic Fluroscopic Study"*

2007- American Society of Biomechanics *"Point Markers Versus Cluster Triads: Multi-Segmental Foot Model Performance is Insensitive to the Architecture of the Reflective Markers Used in Optical Motion Analysis"*