Prolonged sitting, standing, and the sit-stand paradigm for office workers: An investigation into lumbar spine intervertebral joint load distribution

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Over the past 20 years, sit-stand workstations have become more and more prevalent in the office work environment. A sit-stand workstation is any workstation that allows the user to perform their office work in either a seated or standing position with minimal disruption when switching between the two. This thesis explored the potential benefit of sit-stand workstations from a worker back discomfort and productivity perspective; however, the main goal of this thesis was to explore the potential benefit of sit-stand workstations with respect to low back injury prevention. A review of the current literature was conducted (Chapter 3). This review concluded that using a sit-stand workstation likely reduces worker discomfort and has a neutral impact on productivity. The review also found that there is little evidence on whether or not sit-stand workstations can reduce the risk of low back injury associated with prolonged sitting. The first experimental study (Chapter 4) in this thesis confirmed the potential of sit-stand workstations to reduce worker discomfort without reducing productivity. The first experimental study also found significantly different kinematics and kinetics while working in a sit only, stand only, and sit-stand paradigm. Sitting generally resulted in a more flexed lumbar spine compared to standing, with lower levels of compressive spine loading. The second experimental study (Chapter 5) explored the mechanical behaviour of annulus tissue from the intervertebral disc. An understanding of annulus tissue mechanical behaviour is a necessity when exploring potential injury pathways associated with prolonged sitting, standing, and the sit-stand paradigm. The second study found that annulus material properties varied by region of the annulus from which they were obtained. The study also found that when material testing annulus tissue, the means by which the boundary conditions were applied to the tissue affected the derived materials

properties. This consequently affects how the annulus should be modeled numerically. Results of the second study were used to create a numerical model of the intervertebral disc that was used in the third study to further explore the potential benefits of sit-stand work from a low back injury prevention perspective. The third experimental study (Chapter 6) showed that working in a sit-stand paradigm has the potential to reduce peak strain in the intervertebral disc, thus reducing injury potential. Sit-stand work is likely beneficial from an injury perspective beyond just reducing the total time spent sitting throughout the workday.

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Chapter 1 - Introduction

Sedentary and light intensity occupations are increasing in the industrial sector coinciding with a reduction in moderate intensity jobs (Church et al., 2011). For some occupations, sedentary work comprises over 80% of the workday (Toomingas et al. 2012). For many of these workers, it is not uncommon to remain seated for well over an hour straight without standing. Using call center workers as an example, Toomingas et al. (2012) found that less than 2 in 5 workers follow an Ontario Ministry of Labour suggestion for between 5-10 minutes of standing rest breaks for each hour of sitting computer work (Ontario Ministry of Labour 2005). This sedentary behaviour has been associated a number of negative overall health outcomes, including increased risk of obesity, diabetes, and cardiovascular disease (Hu 2003; Mummery et al. 2005). Specifically regarding obesity, Chau et al. (2012) reported that workers with sedentary jobs had a significantly higher overweight/obesity risk when compared to workers with non-sedentary jobs.

In addition to overall negative health outcomes, both prolonged sitting and prolonged standing have been explicitly associated with increased low back discomfort and/or pain (Fenety and Walker 2002; Gregory and Callaghan 2008a; Tissot et al. 2009). Furthermore, developing pain while sitting has previously been associated with increased lumbar spine flexion (O'Sullivan et al. 2006). Lumbar spine flexion, relative to quiet standing, while sitting in an office chair (Alexander et al. 2007; Beach et al. 2008) can potentially pose an injury risk. Hollingsworth and Wagner (2013) showed that spine flexion causes increased strain in the posterior intervertebral disc. This increase in strain is a potential injury mechanism for disc herniation.

Office workers are often required to perform their job at the same workstation for prolonged periods in order to meet productivity demands. As a result, they are sitting or standing, depending on workstation height, for prolonged periods. Despite the evidence supporting the negative effects associated with prolonged sitting, a recent review of the literature surrounding the effectiveness of workplace strategies introduced to reduce prolonged sitting has found the current literature is still too sparse to establish conclusions (Chau et al. 2010). Introducing standing only workstations may seem to be an obvious workplace strategy to reduce sitting; however, Tissot et al. (2009) found that standing without the freedom to sit is also associated with an increase in the prevalence of reported low back pain.

One strategy currently employed to alleviate the increased discomfort/pain associated with sitting and standing is to introduce workstations that allow a worker to perform the same task sitting or standing with minimal interruption to his/her workday (sit-stand workstations). Sit-stand workstations allow the worker to periodically alternate between sitting and standing throughout the day (sit-stand paradigm). It is not entirely clear when the first sit-stand workstation was introduced into an office setting; however, to this author's knowledge the first field study concerning the effectiveness of sit-stand work was presented in the mid 1990s (Nerhood and Thompson 1994). Since that time, over a dozen scientific studies have been conducted on the topic of sit-stand workstations in an office setting. A recent review concluded that sit-stand workstations are most likely effective at lowering low back discomfort (Karakolis and Callaghan 2014). This review forms Chapter 3 of this thesis.

Mechanical damage to annulus tissue in the intervertebral disc has been identified as one potential source of low back pain (Boos et al. 1995; Maezawa and Muro 1992), with approximately 40% of low back pain cases attributed to internal disc disruption (Schwarzer et al. 1995). It is theorized that the effectiveness of the sit-stand paradigm results from changes in the loading environment of the lumbar spine intervertebral discs between sitting and standing (Karakolis and Callaghan 2014). Therefore, the overarching goal of this thesis was to examine changes in lumbar spine intervertebral disc annulus loading between sitting and standing in office workers.

<u>Global Objective:</u> The thesis aimed to answer the following question, from an intervertebral joint mechanics perspective, are there advantages to alternating between sitting and standing throughout a day of office work beyond simply reducing the amount of total time spent sitting?

The thesis was broken up into 3 separate research studies (Figure 1-1) and a critical review of the sit-stand literature. The critical review helped define the key benefits and potential issues with the sit-stand work paradigm, as well as frame the broad scope of the problem this thesis aimed to explore. The first research study characterized *in vivo* joint loading and lumbar spine kinematics during prolonged sit-stand work. This study provided some answers to the issues that were raised in the review and also began to characterize joint loading while working in a sit-stand paradigm. The second study was an *in vitro* study mechanically testing samples of porcine annulus tissue under biaxial tensile load. This study was conducted to determine material properties for the intervertebral disc for the purpose of being used in a numerical model. The final study developed a numerical model that was used to answer the question posed in the global objective by evaluating peak strain in the annulus of the intervertebral disc, incorporating the outcomes of the first two studies as input parameters in the model.

The first study (Chapter 4) was an *in vivo* study of 24 university-aged individuals performing simulated office work. The participants performed simulated office work while sitting for a prolonged period (1 hour), while standing for a prolonged period (1 hour), and while alternating between sitting and standing (15 min sitting to 5 min standing x 3 = 1 hour). The second study was divided into two parts: Study 2-A and Study 2-B. Both parts are presented together in Chapter 5. Both parts were *in vitro* studies that characterized the material properties of isolated porcine intervertebral disc annulus samples. Study 2-A focused on the material properties of both an individual annulus layer and a bi-layer annulus sample. Study 2-B focused on the material properties of the inter-lamellar matrix, which attaches adjacent layers of the annulus, specifically under shear loading. The third study examined the effects of vertebral posture changes, disc height loss, and joint center of rotation migration on the load distribution in the intervertebral disc. The final study was accomplished using a finite element model (FEM) of a porcine functional spinal unit (FSU).

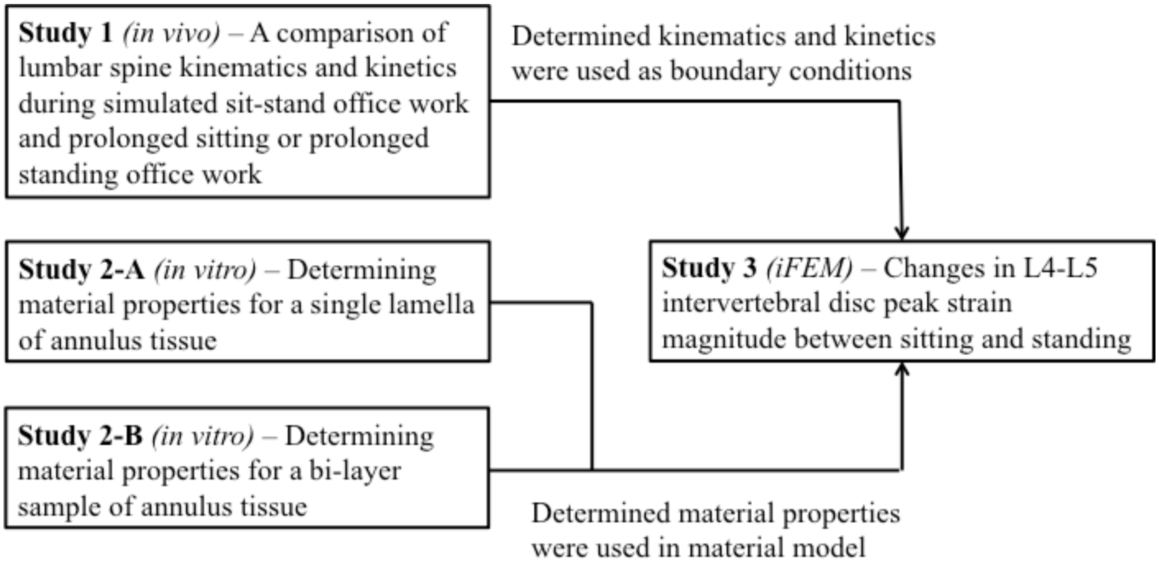

Figure 1-1 - Flowchart outlining the logical connections and titles of the studies for this thesis.

The specific hypotheses for each of the studies are listed here as a summary, along with a brief rationale for each. Each hypothesis is listed again within the chapter specifically describing the corresponding study.

Study 1 – A comparison of lumbar spine kinematics and kinetics during simulated sit-stand office work with prolonged sitting and prolonged standing office work

1) Sit-stand work will positively influence both seated and standing lumbar spine mechanics when compared to either posture performed in isolation.

   Rationale: Lumbar spine flexion has been shown to increase during prolonged sitting (Sanchez-Zuriaga et al. 2010) and prolonged standing (Gregory and Callaghan 2008a), potentially as a result of tissue creep. Intermittent bouts of standing between sitting periods may reduce the potential effects of tissue creep on lumbar spine posture.

2) Sit-stand work will reduce low back discomfort when compared to either posture performed in isolation.

   Rationale: Altered mechanical loading, due to creep in the passive structures in the lumbar spine, has been suggested as a possible cause of discomfort during static postures (Gregory and Callaghan 2008a). Altering postural exposures between sitting and standing, in an attempt to reduce potential tissue creep, may result in less discomfort.

3) Sit-stand work will not reduce productivity when compared to either posture performed in isolation.

   Rationale: The positive effects of reduced discomfort will balance the adverse effects of switching postures on performance.

Study 2 – Determining material properties of the porcine intervertebral disc

Part A

1) For both single layer and bi-layer samples, loading magnitude will not have a significant effect on elastic modulus.

   Rationale: Previous work has treated a single annulus layer as a linear elastic material (Holzapfel et al. 2005). Therefore, assuming a linear response, elastic modulus should not change with respect to loading magnitude unless damage is being induced. The protocol selected for this study has been selected to avoid any likelihood of inducing significant damage, since target strain will not exceed strains shown to be within the physiological range normally applied to the spine (Schmidt et al. 2009).

2) For both single layer and bi-layer samples, elastic modulus determined using equal orthogonal loads during biaxial loading will be significantly different from elastic modulus determined using unequal orthogonal loads.

   Rationale: The annulus is composed of tensile load bearing collagen fibers embedded within a ground substance. Assuming these fibers deform in response to the combination of the orthogonal loading components, this hypothesis assumes that changing the loading components from equal to unequal will cause a different response from the fibers and therefore change the elastic modulus.

3) For both single layer and bi-layer samples, the region of the annulus from which the tissue sample was obtained will impact elastic modulus.

   Rationale: The elastic modulus for annulus tissue samples taken from the anterior of the intervertebral disc will be greater than samples from the posterior of the disc since the lordotic shape of the spine likely results in larger tensile stresses in the anterior portion of the disc when the spine is in a neutral posture. The elastic modulus for annulus tissue samples taken from the superficial layers of the annulus will be greater than samples from the deep layers since the superficial layers likely are loaded with larger tensile stresses due to the geometrical arrangement relative to the joint center of rotation. This hypothesis and rationale agrees with previous work by Gregory and Callaghan (2011b) looking at a stress-stretch ratio in a two-layer annulus sample.

Part B

1) The shear modulus of the inter-lamellar matrix will be impacted by the radial location in the annulus and depth of the tissue sample.

   Rationale: Since the inter-lamellar matrix is loaded with similar principle stresses as the adjacent lamellae, regional variation in shear modulus should follow the same trends as the lamellar elastic modulus regional variation (see rationale for Study 2 – Hypothesis 1).

2) Loading magnitude will have a significant effect on the shear modulus.

   Rationale: Combined torsion and normal loading has been shown to accelerate the susceptibility for injury to the intervertebral disc (Drake et al. 2005). This hypothesis is based on the assumption that the annulus has a lower tolerance to shear loading when compared to normal loading. Therefore, shear loading to the same displacement magnitude as the normal straining study (Part A), will result in damage to the inter-lamellar matrix and a change in the measured shear modulus.

Study 3 – Changes in L4-L5 intervertebral disc peak strain location and magnitude between sitting and standing: A finite element study

1) When compared to prolonged sitting, spine loading and posture associated with prolonged standing will result in lower peak strain magnitude and a peak strain location located deeper within the annulus.

   Rationale: Compressive forces may lead to increased pressure in the intervertebral disc nucleus, causing an increase in tension in the surrounding annulus. Lower magnitude compressive forces in the low back have been reported during standing compared to sitting (Callaghan and McGill 2001). Consequently, in the model, lower compressive force during standing will result in lower nucleus pressure, lower tension in the annulus, and ultimately lower peak strain.

   Lumbar flexion has been shown to increase during both prolonged sitting and prolonged standing (Sanchez-Zuriaga et al. 2010; Gregory and Callaghan 2008a), with a lower magnitude of increase during standing. Less lumbar flexion in standing may result in a deeper peak strain location within the annulus, since geometrically, a greater level of flexion will cause the greatest change in length for the most superficial levels of the annulus.

2) Joint center of rotation migration to the posterior of the intervertebral disc will result in lower peak strain on the annulus.

   Rationale: Posterior migration of the joint center will result in lesser elongation of the annulus tissue on the posterior surface of the annulus during flexion, leading to lower peak strain.

Chapter 2 – General Literature Review

Although the topic covered in this thesis document is the use of sit-stand workstations in an office setting, the three approaches taken to explore the topic are extremely diverse. As such, the topics covered in this general review of the literature are equally diverse. This thesis attempts to approach the problem of sit-stand work using three basic approaches: *in vivo*, *in vitro*, and *in silico*. Relevant literature for each type of approach is presented in this chapter. *In vivo* literature is presented with the focus on discomfort and pain, kinematics, and kinetics. *In vitro* literature is presented with the focus on spine anatomy, mechanical structure and function, intervertebral disc (IVD) injury studies, creep, and mechanical testing of annulus tissue. *In silico* literature is presented with the focus on finite element (FE) modeling of the spine.

2.1 PROLONGED SITTING: POTENTIAL FOR DISCOMFORT AND PAIN

Prolonged sitting while performing office work has been consistently shown in the literature to be associated with low back discomfort (Grondin et al. 2013; O'Keeffe et al. 2013; Gregory et al. 2006) and chronic low back pain (Spyropoulos et al. 2007). As little as one half hour of prolonged sitting can result in an increased level of low and mid back discomfort (Grondin et al. 2013) and sitting for more than 6 hours per day at work has been associated with chronic low back pain (Spyropoulos et al. 2007).

Grondin et al. (2013) measured perceived low back discomfort using a visual analog scale for healthy participants while sitting in a standard chair for 30 minutes and compared it to sitting in a chair with a lumbar support for the equivalent period of time. The Grondin et al. (2013) study reported an increase in low back discomfort from a baseline discomfort of 2.9 mm to 4.5 mm for both the standard and lumbar supported chairs. For mid back discomfort, the reported increase was from a baseline of 2.1 mm to 4.8 mm and 5.9 mm for the standard and lumbar supported chairs respectively.

For low back pain patients, O'Keeffe et al. (2013) found that sitting for one hour in a standard chair resulted in a significant increase in low back discomfort. The O'Keeffe et al. (2013) study used a body part discomfort scale with discrete increments of zero to five, with zero representing no discomfort and five representing pain/extreme discomfort. Participants in their study reported increases in perceived discomfort from a baseline of 1 to a discomfort of 3 after one hour.

When comparing healthy participants sitting for one-hour on an armless office chair versus one-hour on a stability ball, Gregory et al. (2006) found that while sitting on the ball the participants reported significantly higher increases in low back discomfort. However, the study also reports a significant increase in perceived discomfort in sitting on the office chair from baseline, indicating that although sitting on a ball results in higher levels of discomfort, sitting on a chair also causes discomfort.

Beyond the laboratory studies discussed, a 2007 study by Spyropoulos et al. found that of the 648 Greek office workers they surveyed, 37% reported chronic low back pain. Using multiple logistic regression models, Spyropoulos et al. (2007) reported that sitting time of greater than 6 hours was a significant determinant in whether or not an office clerk had chronic low back pain.

2.2 PROLONGED STANDING: POTENTIAL FOR DISCOMFORT AND PAIN

Studies have shown a strong association between low back pain and standing occupations (Andersen et al. 2007; Roelen et al. 2008). Length of time spent on one's feet has been shown to have a positive correlation with development of low back pain (Kim et al. 1994).

In a two-year prospective study of a general working population, Andersen et al. (2007) surveyed over 4000 participants. Among their findings, Andersen et al. (2007) found both heavy lifting and prolonged standing to be predictors of low back pain. Specifically, they report that standing more than 30 minutes out of each hour was a strong predictor of low back pain.

In the manufacturing industry, standing work is commonplace. In a study of 867 manufacturing industry workers by Roelen et al. (2008), it was found that standing work predicted low back pain, as well as leg pain and thoracic pain. Interestingly, Rolen et al. (2008) found that sedentary work also predicted low back pain.

Tissot el al. (2009) conducted a study surveying 4493 standing workers and 3237 sitting workings in Quebec. Among the interesting findings reported by Tissot et al. (2009) was 24.5% of the workers surveyed reported significant low back pain. Of particular interest with respect to sit-stand work, Tissot et al. reported that standing without the freedom to sit was significantly associated with low back pain. From their findings, it is not certain that the freedom to sit provided by a sit-stand workstation would reduce the incidence of low back pain; however, this is a plausible assumption that may be made.

Specifically pertaining to currently implemented or recently studied standing work interventions, there is evidence that low back pain can be reduced during prolonged standing through the use of sloped surfaces to stand on (Nelson-Wong and Callaghan 2010a) or exercise interventions (Nelson-Wong and Callaghan 2010b). However, neither study was able to reduce the incidence of low back pain to zero. Presently, there appears to be no effective means of completely preventing low back pain during prolonged standing.

In 2010, Nelson-Wong and Callaghan published two separate studies looking at ways to reduce low back pain during prolonged standing work. In their study of sloped surfaces (2010a), they report that low back pain scores were reduced by 59.4% for low back pain developers using the sloped surfaces. In the Nelson-Wong and Callaghan (2010b) study of an exercise intervention in the form of a progressive exercise program, the authors found a 45.9% reduction in low back pain in the exercise group when compared to controls.

Given that low back pain seems to occur during both prolonged sitting and prolonged standing, this thesis examined an alternative to sitting and/or standing. The alternative is a sit-stand paradigm. Perhaps alternating between sitting and standing is an effective tool in varying kinematics and preventing low back pain.

2.3 OBJECTIVELY MEASURING DISCOMFORT OR PAIN

Although discomfort and pain are two different concepts, there is likely a link between them. As mentioned in the Sit-stand workstation review (Chapter 3), a study by Hamberg-van Reenen et al. (2008) reported evidence that musculoskeletal discomfort may be a predictor of future pain. Unfortunately, the problem with rating both discomfort and pain is the subjective nature of the rating. Referencing ahead to Chapter 3 again, there are alternative objective measures that may be associated with the subjective measure of perceived pain or discomfort. For example, in a review article by De Looze et al. (2003) it was reported that there appears to be a clear association between seat pan pressure distribution and rating of perceived discomfort while sitting. This finding however is not specific to the low back.

An alternative group of objective measures quantifying postural movements have previously been used to examine the potential causes of low back pain: shifts, drifts, and fidgets. Consequently, one or more of these methods may also be a potential surrogate measure for perceived discomfort or pain. Gallagher et al. (2011) used a method similar to that of the method previously described by Duarte and Zatsiorsky (1999) to examine if there were differences in postural control between pain developers and non-pain developers during unconstrained quiet standing. With respect to shifts, drifts, and fidgets, Gallagher et al. (2011) concluded that pain developers and non-pain developers do not use different postural changes during unconstrained quiet standing. Although Gallagher et al. (2011) were not able to conclude that postural changes either caused or reduced pain development; they did conclude that body weight shift frequency and perceived pain both increased over time.

In 2010, Dunk and Callaghan published a study examining a group of sixteen participants whom developed low back pain as a result of prolonged sitting and a group of age and gender matched controls. The Dunk and Callaghan (2010) study found that every participant fidgeted on average once every 40 to 50 seconds; however, the low back pain group shifted a significantly greater number of times compared to the matched controls, during their 90 minutes of sitting. The study also found that low back pain developers demonstrated larger amplitudes of both shifts and fidgets compared to the matched controls.

None of the studies described in the preceding paragraphs (Gallagher et al. 2011; Dunk and Callaghan 2010; Duarte and Zatsiorsky 1999) have made a direct causal link between pain development and postural development, with Gallagher et al. (2011) going so far as saying it does not appear to be the case. However, each study did report at least some form of association between postural changes and pain; therefore, these measures still may be of value as a surrogate pain measure.

2.4 SITTING AND STANDING: LOW BACK KINEMATICS

Relative to anatomical position (or quiet standing), in a seated position the hips are flexed, the pelvis rotates in a posterior direction, and the lumbar spine is put into flexion. Although lumbar flexion is not necessarily always associated with the seated position, there is evidence to show that lumbar spine angles have an association with hip flexion (Eklund and Liew 1991), and as a result, lumbar flexion is often associated with sitting.

During quiet standing, the lumbar spine has a lordotic shape. This lordosis can cause some ambiguity when referring to spine kinematics. The terms extension, flexion and neutral are often used to describe spine posture. For the purposes of this thesis document, when referring to the entire lumbar spine (L1-L5), a neutral posture will refer to the lordotic shape of the spine during quiet standing. Conversely, when referring to just the functional spinal unit (FSU) L4-L5, the term neutral will refer to a position where the vertebral body of L4 and L5 are axially aligned. This can be confusing at times, since based upon these definitions, during quiet standing the lumbar spine is considered neutral. However, the L4-L5 FSU is in a relative extended position during quiet standing. In sitting, the lumbar spine is in flexion; however, depending upon the degree of lumbar flexion, the L4-L5 FSU may be in a flexed or neutral, or even slightly extended position.

Previous work has shown both posterior rotation of the pelvis and lumbar spine flexion, relative to standing neutral, in both automobile sitting (De Carvalho and Callaghan 2012) and office sitting (Alexander et al. 2007). In both automobile and office sitting, lumbar spine flexion has been shown to be approximately 40 degrees. Beach et al. (2008) showed that average male lumbar flexion angle while sitting in an office chair was approximately 60% of their total flexion range of motion (ROM). McGill and Fenwick (2009) reported that while sitting in airplane seats, most participants reached 97% of their total ROM.

In terms of low back/pelvis kinematics and pain, there is also evidence of a link between pain and both lumbar flexion and posterior pelvis rotation. O'Sullivan et al. (2006) reported participants that develop pain in response to sitting have been shown to have increased posterior pelvis rotation and increased lumbar spine flexion.

2.5 SITTING AND STANDING: LOW BACK KINETICS

Although sometimes thought of as relatively benign activities, both sitting and standing have been shown to result in lumbar spine loading equivalent to over two times body weight. In 2001, Callaghan and McGill (2001b) reported an average compressive lumbar spine load of 1076 N for standing and an average compressive lumbar spine load of 1698 N for unsupported (no back rest) sitting. The average participant body mass for the Callaghan and McGill study was 74.4 kg. That average body mass equates to an average body weight of 730 N, meaning during unsupported sitting compressive lumbar spine loading exceeds two times body weight. To put this into context, compared to common lifting tasks this level of spine loading is relatively low.

Recent spine compressive loading, reported by Parkinson et al. (2012), estimate average compressive force to be either 3703 N or 3769 N depending on approach taken to come up with the estimate. In the Parkinson study, participants were lifting weights of 7.6 kg or 9.7 kg from approximately waist height to approximately shoulder height. Previously, Kingma et al. (2006) reported compressive lumbar spine loads of between 4000 and 5000 N depending on lifting strategy used. The Kingma study values are estimated for subjects lifting a mass of 20 kg.

Lifting has repeatedly been shown to be a cause of low back pain and injury, with the National Institute for Occupational Safety and Health (NIOSH) going so far as publishing an equation for safe lifting limits (Center for Disease Control and Prevention, 1994). Although lumbar spine loading is considerably lower during sitting and standing, compared to lifting, the possibility still exists that even the lower sitting and standing loads may cause injury. The injury mechanism associated with sitting and standing may be a result of the prolonged nature of these activities combined with the non-neutral postures adopted, particularly during sitting.

2.6 SPINE ANATOMY, MECHANICAL STRUCTURE, AND FUNCTION

The human spine is composed of 24 articulating vertebrae and 9 fused vertebrae (Striano 2011). The articulating vertebrae are divided into three regions: cervical, thoracic, and lumbar. The fused vertebrae are divided into two regions: sacrum and coccyx. Between the articulating vertebrae lie intervertebral discs. Each disc allows for slight movement between vertebrae, act as ligaments to hold the vertebrae together, and finally serve as shock absorbers during impacts. This thesis will generally focus on the low back and therefore discussion is centered on the lumbar region of the spine.

Chronic low back pain can be caused by a number of different reasons including tissue damage to bone, muscle, ligament, and tendon; however, the most prevalent cause of chronic low back pain is internal disruption of the intervertebral disc. Approximately 40% of patients with chronic low back pain are diagnosed with an internal disc disruption (Schwarzer et al. 1995). The most common discs to become injured are the disc between L4-L5 vertebrae and the disc between L5-S1 vertebrae (Schwarzer et al. 1995). For this reason, this thesis predominantly discuses the L4-L5 disc.

It is very difficult to study the intervertebral disc in isolation since the loading environment the disc experiencing is heavily influenced by the structures that it is surrounded by and attached to. A more common structure to study is a function spinal unit (**Figure 2-1**). A function spinal unit consists of two adjacent vertebrae and an intervertebral disc.

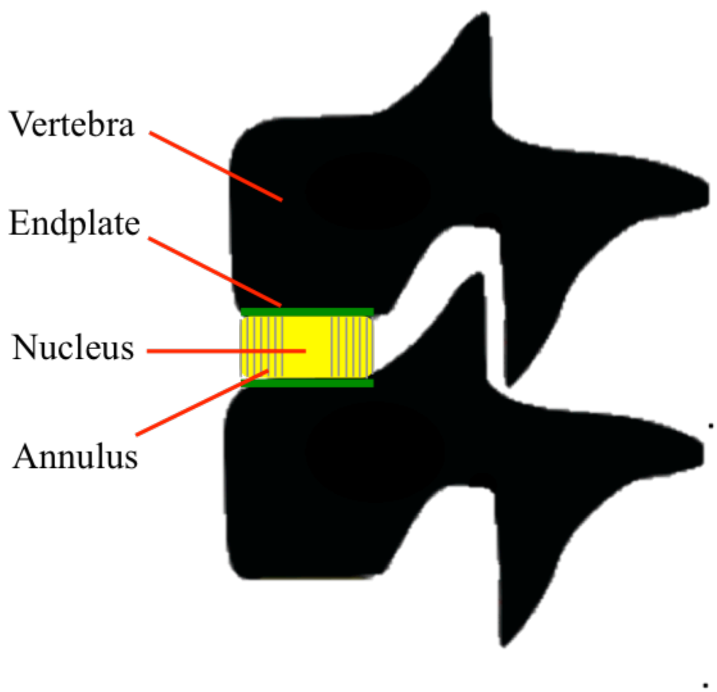

Figure 2-1 – Schematic representation of spine anatomy

The intervertebral disc consists of a nucleus pulposus and an annulus fibrosus. The annulus is a composite lamellar structure (**Figure 2-2**). Previous literature reports the human annulus structure to be composed of 15-25 layers (Cassidy et al. 1989; Marchand and Ahmed 1990). Each layer of the annulus is composed primarily of aligned collagen fiber bundles, along with water, proteoglycans, and non-collageneous proteins (Holzapfel et al. 2005). Layers of the annulus are bound together by an inter-lamellar matrix, with collagen fiber bundles crossing multiple annular layers (Veres et al. 2010). In addition to not being a homogeneous material, the annulus also exhibits regional structural and mechanical variations, with respect to location (Tsuji et al. 1993; Skaggs et al. 1994). Damage to this annulus structure of the intervertebral disc is often referred to as disc injury or herniation.

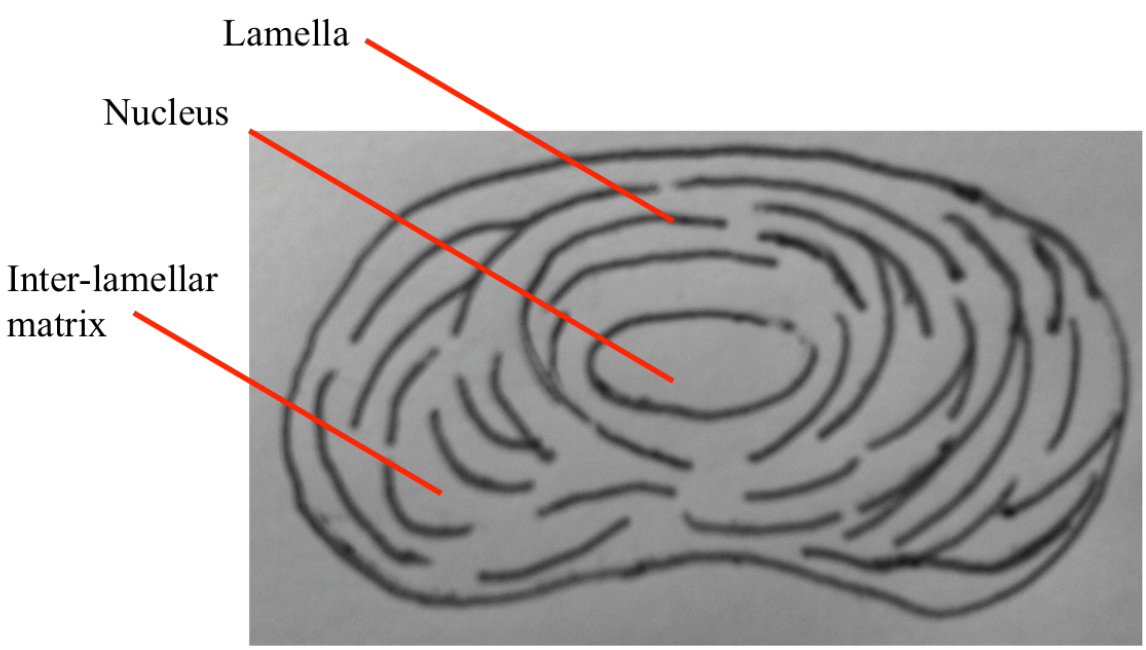

Figure 2-2 – Schematic representation of a transverse annulus slice

2.7 IVD INJURY STUDIES

Intervertebral disc herniation (IVD) occurs when material from the nucleus pulposus breaches the surrounding composite laminate structure - the annulus fibrosus (Adams and Hutton 1985). In order for nucleus material to breach the annulus, an internal disruption must occur within the disc, specifically within the layers of the annulus nearest the nucleus. A study by Veres et al. (2008) showed that an internal disc disruption, which results from an acute hyper-physiological pressure increase within the disc, usually begins near the site where the annulus attaches to the vertebral body endplate.

A number of other *in vitro* studies have used an alternative approach to study the link between mechanical loading of the disc and disc herniation (Parkinson and Callaghan 2009; Drake et al. 2005; Callaghan and McGill 2001a; Adams et al. 2000; Adams and Hutton 1983; Kuga and Kawabuchi 2001; Simunic et al. 2004; Yates and McGill 2004). This approach generally involves mechanically testing functional spinal units under combined compressive and repetitive flexion/extension loading to create a disc herniation.

Callaghan and McGill (2001a) dynamically tested porcine functional spinal units in a combined loading scenario with axial compressive loading and pure flexion/extension moments. Loading was repetitive at a rate of 1 Hz to a maximum number of cycles, 86400. Their study found that disc herniation occurred with relatively low levels of joint compression and high repetitions of flexion/extension. They also reported that increases the level of compression resulted in more frequent and more severe disc injuries.

Parkinson and Callaghan (2009) studied the effect of varying the level of compressive loading in combination with repetitive flexion loading. The study observed that under lower levels of compressive loading, in combination with repetitive flexion, a disc injury was more likely to occur. Conversely, under higher levels of compressive loading, a vertebral facture is more likely.

Repetition and magnitude of loading are not the only factors that have been shown to cause disc injury. Drake et al. (2005) showed that prolonged static loading could also increase the likelihood of an intervertebral disc injury. Drake et al. (2005) loaded two groups of functional spinal units under repetitive combined compressive and flexion/extension loading. One group was also loaded under 5 N/m of static axial torque. Drake et al.'s (2005) findings showed that the group loaded under static torque was significantly more likely to herniate due to an otherwise identical loading protocol (71% versus 29%).

Prolonged sitting does not cause the type of repetitive loading used by Callaghan and McGill (2001a) or Parkinson and Callaghan (2009) to create disc herniation. Instead, prolonged sitting more likely results in prolonged static flexion loading of the lumbar spine. Although the Drake study did not specifically look at static flexion loading, it did show that static loading does have the potential to increase the likelihood of intervertebral disc herniation. The mechanism behind how static loading may cause tissue failure is discussed in the following section.

2.8 PROLONGED TISSUE LOADING: CREEP

Creep is a term used to describe the tendency of a material to slowly deform under static mechanical stresses below the material's yield strength (Beer and Johnston 2004). This deformation can either be temporary, lasting only as long as the static mechanical stress is acting on the material, or permanent. Creep can cause a material to yield and ultimately fail if the magnitude of mechanical stress is sufficiently high or the length of time is sufficiently long.

The concept of yield is relevant to a number of living tissues (Fung 1993). Of specific interest in this thesis document is how it applies to the intervertebral disc during prolonged sitting and standing. As mentioned previously in this chapter, both prolonged sitting and prolonged standing result in mechanical loading of the lumbar spine joints (Callaghan and McGill 2001b). This mechanical loading must result in mechanical stress being placed on the intervertebral disc.

Due to the mechanical structure and geometry of the intervertebral disc, the flexion associated with prolonged sitting (Alexander et al. 2007) must cause a mechanical stress in the posterior region of the annulus (**Figure 2-1**). However, the potential magnitude of mechanical stress and or strain associated with sitting have yet to be reported in the literature. Both sitting and standing have also been shown to cause a compressive load on the intervertebral disc (Callaghan and McGill 2001b). Since the disc is shaped as a pressure vessel with the semi-permeable annulus containing the nucleus, compressing the disc will also result in a mechanical stress on the annulus. Again, the magnitude of mechanical stress and or strain associated with the compressive loading during both sitting and standing has yet to be reported in the literature.

Therefore this thesis aimed to be the first known study to estimate the mechanical stress and strain in the annulus of the intervertebral disc with both prolonged sitting and standing.

2.9 MATERIAL TESTING OF ANNULUS TISSUE

Material testing of annulus tissue has revealed insights into the structure and function of the annulus. For example, in addition to not being a homogeneous material it also exhibits regional structural and mechanical variations, with respect to location (Tsuji et al. 1993; Skaggs et al. 1994).

Tsuji et al. (1993) studied the intervertebral disc in bovine and porcine tails. Structurally, they found that the collagen content decreases from the outer to the inner layers of the annulus. The change in collagen content was associated with changes in water content and mechanical behaviour under loading.

Single lamella annulus specimens were first tested under uniaxial loading by Skaggs et al. (1994). Skaggs et al. (1994) found significant regional variations in tensile properties in both the radial and circumferential directions. Circumferentially, the anterior region was stiffer than the posterior. Radially, outer annulus was stiffer than inner annulus.

More recent attempts to characterize the material properties of the annulus have also involved uniaxial tensile testing of small tissue samples (Holzapfel et al. 2005; Zhu et al. 2008).

Holzapfel et al. (2005) tested single layer annulus samples at three different strain rates. Samples were submerged in 0.15 mol/l NaCl solution and temperature was maintained at 37 degrees Celsius. Holzapfel reported three calculated moduli: E(low) – 0-0.1 MPa; E(medium) – 0.1-0.5 MPa; and E(high) – 0.5-1 MPa. When characterizing the tensile behaviour of the collagen fibers within the annulus lamellae, Holzapfel reported moduli ranging from 28-78 MPa.

Zhu et al. (2008) studied the annlus at two different levels of the lumbar spine, L4-L5 and L5-S1. Zhu found that structurally and mechanically there were no differences between the adjacent levels of the spine. Zhu also found that the fiber orientation of the collagen within each layer gradually changed along the radial direction. This structural change in fiber orientation may explain some of the changes in mechanical properties previously reported by Skaggs and Holzapfel.

Although the work previously discussed has provided valuable insight into the structural and mechanical variations within the annulus, a major limitation of the work is the uniaxial nature of the applied load. Under compressive loading, the annulus tissue is loaded by an outward pressure of the nucleus. Therefore the load is multi-directional tension. A more appropriate means of testing annulus tissue is biaxial tensile testing. The most comprehensive study of annulus mechanics under biaxial tension were completed by Gregory and Callaghan (2008b; 2011a; 2011b).

In 2011, Gregory and Callaghan published two studies examining the behaviour of single and bi-layer samples of porcine annulus tissue under biaxial tensile loading. Unfortunately, a limitation in the boundary conditions of the method of applying the load in the Gregory and Callaghan studies (2011a; 2011b) only allowed them to report stiffness of the samples rather than moduli. This thesis builds very closely off the work done by Gregory and Callaghan (2011a; 2011b), to determine moduli of both single and bi-layer samples of annulus under biaxial tensile loading.

2.10 SPINE FE MODELS

To date, there have been a number of finite element (FE) models created for the intervertebral disc to study a wide range of relevant scientific questions (Tang and Rebholz 2011; Schmidt et al. 2007; Schmidt et al. 2012; Zander et al. 2009). However, to this author's knowledge no finite element disc models have been applied to the questions surrounding prolonged sitting and standing. Therefore, this section will describe a few previous models with specific focus on model development.

Tang and Rebholz (2011) created a finite element model containing two intervertebral discs, L3-L4 and L4-L5. The model was used to study the effect of lumbar fusion on adjacent disc generation. The nucleuses in the discs of Tang and Rebholz's (2011) model were made up of an incompressible material. The nucleuses were surrounded by a composite annulus structure. The annulus was composed of a homogenous ground substance reinforced by collagen fibers. The ground substance had a constant elastic modulus of 1.35 MPa and the annulus fiber material properties were varied depending on the level of degeneration being studied.

A model developed by Schmidt et al. (2007) has been used in a number of finite element studies (Schmidt et al. 2007; Schmidt et al. 2012). The nucleus in the Schmidt et al. (2007) model is a nearly incompressible and hyper-elastic fluid described by a Mooney-Rivlin material law. The annulus is composed of a homogeneous ground substance reinforced with a collagen fiber network. In total there are eight layers of collagen fibers with fiber orientation varied from 24 degrees to the 46 degrees progressing radially from outer most to the innermost layer. The material properties for the annulus were calibrated by comparing to experimental data in order to maximize agreement between model predictions and experimental results.

Zander et al. (2009) developed a model of the entire lumbar spine containing 5 intervertebral discs to examine the effects of artificial disc replacement. The discs in the Zander et al. (2009) model were created similarly to the two previously described models. Again the nucleus was modeled as an incompressible fluid and the annulus was modeled as a ground substance with a network of reinforced annulus fibers. In the Zander et al. (2009) model, the ground substance is modeled as NeoHookean and the fibers are modeled as Progressive nonlinear springs.

Based upon the described models, it is safe to say that there still remains no standard practice of modeling the intervertebral disc. Each model has slight differences with respect to the other models presented and there are strengths and limitations to each modeling technique.

2.11 SUMMARY

Based upon a general review of the literature, it appears as though working in a prolonged sitting or a prolonged standing posture both are likely to result in increasing discomfort. Working in a sit-stand paradigm, while alternating between sitting and standing periodically, may have the potential to reduce discomfort. This topic is explored more thoroughly in the next chapter (Chapter 3).

Beyond discomfort, both prolonged sitting and prolonged standing may have the potential to cause injury. The injury mechanisms may be associated with a combination of prolonged loading and the lumbar spine postures assumed, especially during sitting. Chapter 4 of this thesis explored the lumbar spine posture and loading during prolonged sitting, prolonged standing, and working in a sit-stand paradigm.

Although posture and loading can ultimately be identified as the cause of injury, understanding the mechanical response of the tissue to loading also provides additional information needed to help solve the injury equation. With respect to annulus tissue in the intervertebral disc of the lumbar spine, historically mechanical testing of the tissue has been uniaxial in nature. Biaxial testing, which is more representative of how the tissue is loaded *in vivo*, has recently begun; however, more work still needs to be done to further explore this new loading method. Chapter 5 of this thesis addresses this issue.

Finally, finite element modeling can provide valuable insight into spine disc loading. The technique has previously been used to explore a wide range of practical loading scenarios; however, it has never been used to explore prolonged sitting and prolonged standing. Chapter 6 of this thesis used this technique to explore prolonged sitting, prolonged standing, and sit-stand.

Chapter 3 - The impact of sit-stand office workstations on worker discomfort and productivity: A review

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3.1 INTRODUCTION

Prolonged seated work has been shown to result in increasing worker discomfort with respect to time (Fenety and Walker, 2002, McLean et al., 2001, Callaghan et al., 2010). Adjusting posture at an increased frequency throughout the workday is a proposed strategy used in an attempt to reduce discomfort (Karwowski et al., 1994; Liao and Drury, 2000). Posture adjustment can be accomplished in a range of different ways spanning from interventions as basic as adjusting seating position, to more extreme interventions such as changing whole body posture from a sitting to a standing position, increased breaks (McLean et al., 2001), or treadmill walking while working (John et al., 2009). It is based upon this extreme posture change that the sit-stand paradigm for office work was proposed (Karlqvist, 1998) and implemented. Although the logic behind installing sit-stand workstations in an office setting is based on sound ergonomics theory, historically sit-stand workstations have represented a small market share in North America but given the recent attention to chronic disease and total mortality associated with prolonged sitting (Patel et al., 2010) sit-stand stations have become a rapidly growing market share. Studies by Neerhood and Thompson (1994), Hedge and Ray (2004), and Vink et al. (2009) all showed that workers choose to stand for between 20-30% of their day when provided with a height adjustable workstation, while participating in their study. However, these studies were all for very brief periods (less than one month), and the participants were aware that they were participating in a study. To the contrary, there is also evidence showing a lack of compliance in using sit-stand workstations between six months to over a year after they are installed (Wilks et al., 2006). Through a small survey of companies with sit-stand workstations in Sweden, Wilks and colleagues (2006) found that as few as one in ten workers actually use the sit-stand feature of their workstation on a daily basis. Although there are a number of studies (Nerhood and Thompson, 1994; Roelofs and Straker, 2002; Davis et al., 2009) demonstrating the advantages/disadvantages of properly using a sit-stand workstation, the primary goal of this paper is to assemble a single, clear, compilation of this knowledge to support future evaluations and decisions surrounding adoption of these workstations for widespread use.

In 2012, Vink and Hallbeck proposed the following definitions for comfort and discomfort respectively: "comfort is seen as pleasant state or relaxed feeling of a human being in reaction to its environment" (p. 271); and "discomfort is seen as an unpleasant state of the human body in reaction to its physical environment." (p. 271) Based upon these definitions, comfort and discomfort are not reciprocal terms, and the terms should not be used interchangeably (Zhang et al, 1996). Although measuring the feeling of discomfort is by its very nature subjective, there has been a link found between alternative objective measures (ex. pressure distribution) and subjective discomfort scores (De Looze et al., 2003). This link, combined with logistical limitations of worksite objective measures, has led to discomfort being used as a common outcome measure in assessing the effectiveness of sit-stand workstations. There is also evidence to suggest that musculoskeletal discomfort may be a predictor of future pain (Hamberg-van Reenen et al., 2008). Peak discomfort has been shown as a predictor of low-back, neck, and shoulder pain in a study of 1800 workers from 34 different companies. An important research question to be derived from all this is: does the sit-stand paradigm result in decreased worker perceived discomfort?

Worker productivity is another potential outcome measure that can be used in assessing the effectiveness of sit-stand workstations (Nerhood and Thompson, 1994; Dainoff, 2002; Husemann et al., 2008). Chapter 10 of the United States Department of Labor – Bureau of Labor Statistics (BLS) Handbook of Methods (BLS, 1997) defines productivity as, "output per hour". The BLS Handbook goes on to explain that output is: "measured net of price change and inter-industry transactions." (p. 90) With respect to the scientific and ergonomics literature reviewed here, price change and inter-industry transactions are difficult to obtain. In contrast, in the ergonomics literature office productivity is reported using alternative measures such as total keystrokes, completion of typing tasks, absenteeism rates, etc. Beyond this, many other factors can also contribute to BLS defined productivity (price and inter-industry transactions). Experience, communication, and creativity can also play a role in productivity; however, these concepts are extremely difficult to quantify and are rarely included in the sit-stand ergonomics literature.

There has been work showing a potential association between increasing discomfort and decreasing productivity, as measured by the completion of short typing tests and typing speed (Haynes and Williams, 2008; Liao and Drury, 2000). It has also been suggested that there may be an association between certain postures, other than a traditional sitting posture, and decreased worker productivity (Liao and Drury, 2000). A combination of the potentially opposing associations between increased productivity resulting from decreased worker discomfort in a sit-stand paradigm, and a decrease in productivity resulting from a standing posture leads to the question: does the sit-stand paradigm result in increased worker productivity?

This review is focused on the effectiveness of the sit-stand paradigm. Effectiveness can be measured as decreased worker discomfort and increased worker productivity. Specifically, measures of reduction in discomfort and increases in productivity through the introduction of specialized workstations, which allow for alternating between sitting and standing periodically throughout the office workday (sit-stand workstations), were examined.

3.2 METHODS

3.2.1 Criteria for selecting studies for inclusion

Types of studies

All empirical research studies, which examined the effectiveness of sit-stand workstations or a sit-stand work paradigm in an office setting, were included. Both laboratory and field studies were included. Due to language restrictions, only studies published in the English language were included.

Types of participants

All included studies were performed on participants aged 18 or older. Studies conducted using experienced office workers and/or inexperienced office workers were both included. Studies examining healthy populations and/or populations with current, or a history of, low back pain were included.

Sit-stand workstation interventions

A sit-stand workstation was defined as a workstation that allowed a worker to perform the same task from either a seated or standing position with a self-adjustable worksurface height. Thus, the sit-stand work paradigm consists of a worker performing their duties while periodically alternating between sitting and standing positions throughout the day. All studies included involved a comparison of outcome measures for the sit-stand work condition to either: prolonged seated work, prolonged standing work, or both prolonged seated and prolonged standing work. All studies concerning the intervention of a sit-stand work paradigm were identified.

3.2.2 Search methods for identification of studies

Four databases (PubMed, ScienceDirect, Ergonomics Abstracts and Google Scholar) were searched using the following terms: "sit-stand" AND ("workstation" OR "workstations"). Searches were conducted between the dates of October 10th and October 20th, 2011, and were limited to articles published between 1950 and 2011. Included articles met at least the first three of the following five inclusion/exclusion criteria:

1. Primary research study that examined participants using sit-stand workstations
2. Participants were not an operator in a manufacturing process of any kind. Participants worked in an office setting (ie. VDT users and call center agents) or simulated office work in a laboratory setting
3. Sufficient detail about experimental methods was provided to critically assess quality. Such detail must have included: number of subjects, type of subject population, description of sit-stand paradigm(s) employed, description of randomization/controls, and description of outcome measures.
4. At least one outcome measure was participant subjective discomfort
5. At least one outcome measure was a productivity criteria (ie. keystrokes per minute, errors per keystroke, sick days, break time, etc.)

One additional criteria for the study was also considered, although the following was not deemed an inclusion/exclusion criteria:

6. Discomfort outcome measure included a specific low back discomfort score.

3.2.3 Study selection

The eligibility of each study found through the database searches was assessed by first reviewing the abstract and if there was potential for the inclusion criteria to be met the entire paper was obtained. Relevant data were extracted and the quality of the experimental design and relevance were evaluated. Population characteristics (age, gender, office work experience, history of low back pain), specific intervention paradigm (amount of time standing versus sitting, standing worksurface height, sitting worksurface height), worker adherence to intervention (how well did the worker follow the intervention), and outcome measures (discomfort, productivity, other kinematic measures) were extracted.

The quality of each study was assessed based on four conditions: a) randomization and a control condition in the study design, b) sit-stand intervention, c) worker adherence to intervention, and d) direct industrial applicability of the outcome measures reported. The scoring system was based on the following:

a) Randomization/Control: **(Score = 2)** a sit-stand group and a at least one control group AND subjects randomly assigned to each group; **(Score = 1)** no control group OR no randomization; **(Score = 0)** no control group AND no randomization.

b) Intervention: **(Score = 2)** participants were either instructed to follow a sit-stand ratio or participants were allowed to self select time spent sitting/standing and time spent sitting/standing was measured by the experimenter AND sitting condition was not a high chair; **(Score = 1)** time spent sitting/standing was not measured OR sit was in a high chair; **(Score = 0)** time not measured AND sit was in a high chair.

c) Adherence: **(Score = 2)** participants strictly followed the instructed sit-stand ratio OR for self selected studies, alternated between sitting/standing at least once per day; **(Score = 1)** participant adherence was unclear; **(Score = 0)** participants did not alternate between sitting/standing at least once per day.

d) Applicability: **(Score = 2)** study conducted in the field (ie. not a laboratory study) AND at least one outcome variable either discomfort or productivity; **(Score = 1)** not in the field OR did not have discomfort or productivity as an outcome variable; **(Score = 0)** not in the field AND did not have discomfort or productivity as an outcome.

A high quality study (score = 8) was one that fully met all the quality conditions.

Unfortunately, many of the studies identified did not report results in a manner appropriate for statistical pooling (i.e. they did not report means and standard deviations). Also, there was considerable variation in the implementation of the sit-stand interventions. The ratio of time sitting compared to time standing greatly varied between studies. Due to these limiting factors, a meta-analysis was not included in this review.

3.3 RESULTS

3.3.1 Literature Search

Results of literature search and study selection

The Google Scholar search found 326 articles. The ScienceDirect search found 44 articles, 13 of which were unique and not found in the other database searches. The Ergonomics Abstracts search found 10 articles, four of which were not found in the other databases. The PubMed search found 5 articles, one of which was not found in the other databases. From the searches, a total of 12 studies were identified as meeting at least the first three of five inclusion/exclusion criteria. Screening references cited in the 12 identified studies revealed two additional identified studies for a total of 14 studies.

Criteria met for each identified study

All 14 identified studies met the inclusion criteria concerning a primary research study examining sit-stand workstations (#1), participants not being operators in a manufacturing process (#2), and sufficient detail about experimental methods (#3).

For the criterion stating that at least one outcome measure was discomfort (#4), seven of the 14 identified studies met this criterion. For the criterion stating that at least one outcome measure was productivity (#5), eight of the 14 identified studies met this criterion (**Table 3-1**).

Table 3-1: Inclusion/exclusion criteria met for each study

Study	Criteria				
	1	2	3	4	5
Nerhood 1994	Yes	Yes	Yes	Yes	Yes
Paul 1995a	Yes	Yes	Yes	No	No
Paul 1995b	Yes	Yes	Yes	No	No
Paul 1995c	Yes	Yes	Yes	No	No
Hasegawa 2001	Yes	Yes	Yes	No	Yes
Dainoff 2002	Yes	Yes	No	No	Yes
Roelofs 2002	Yes	Yes	Yes	Yes	No
Hedge and Ray 2004	Yes	Yes	Yes	Yes	Yes
Wilks 2005	Yes	Yes	Yes	No	No
Hedge 2005	Yes	Yes	Yes	No	Yes
Ebara 2008	Yes	Yes	Yes	Yes	Yes
Husemann 2009	Yes	Yes	Yes	Yes	Yes
Vink 2009	Yes	Yes	Yes	Yes	No
Davis 2009	Yes	Yes	Yes	Yes	Yes

Study outcome measures

Five of the identified studies measured time spent performing standing work at sit-stand workstations, two did not, and the remaining seven studies controlled the time standing as a requirement in their experimental design (**Table 3-2**). Seven studies included a discomfort measure. Eight included a worker productivity measure. Three studies included an alertness measure, and three included a frequency of minor posture adjustments (not sitting to standing) measure. Foot swelling and spinal shrinkage were outcomes measures each recorded in a different single study.

Table 3-2: Breakdown of types of outcome measures for each study

STUDY	OUTCOME MEASURE								
	Time Standing	Discomfort			Foot Swelling	Spinal Shrinkage	Worker		
		Whole Body	Low Back	Shoulder/ Upper Extremity			Productivity	Alertness/ Sleepiness	Minor Posture Adjustments
Nerhood 1994	✖	✖	✓	✓	✖	✖	✓	✖	✖
Paul 1995a	N/A	✖	✖	✖	✖	✓	✖	✖	✖
Paul 1995b	N/A	✖	✖	✖	✓	✖	✖	✖	✖
Paul 1995c	N/A	✖	✖	✖	✖	✖	✖	✓	✖
Hasegawa 2001	N/A	✖	✖	✖	✖	✖	✓	✓	✓
Dainoff 2002	✓	✖	✖	✖	✖	✖	✓	✖	✖
Roelofs 2002	✖	✓	✓	✓	✖	✖	✖	✖	✓
Hedge 2004	✓	✓	✓	✓	✖	✖	✓	✖	✖
Wilks 2005	✓	✖	✖	✖	✖	✖	✖	✖	✖
Hedge 2005	N/A	✖	✖	✖	✖	✖	✓	✖	✓
Ebara 2008	N/A	✖	✓	✓	✖	✖	✓	✓	✖
Husemann 2009	N/A	✓	✖	✖	✖	✖	✓	✖	✖
Vink 2009	✓	✓	✓	✓	✖	✖	✖	✖	✖
Davis 2009	✓	✓	✓	✓	✖	✖	✓	✖	✖

*For studies where the time spent standing was incorporated into the experimental design, time standing was an independent rather than dependent variable and was therefore not applicable (N/A).

Quality of included studies

For the identified studies in the review, the average overall quality was scored 5.4/8, with a standard deviation of 1.5 (**Table 3-3**). Generally, the quality of the intervention was very strong. No study received a full score for applicability of the outcome measures. The applicability criterion was an assessment of how appropriate the outcome measures of a particular study were for industrial use. This indicates that although combined results from multiple studies may provide strong evidence for increased sit-stand workstation use, at the present time, no single study can be used to fully quantify either the benefits or drawbacks of sit-stand workstations in the field.

Table 3-3: Score for quality of each study included

	Randomization/Control	Intervention	Adherence	Applicability	Total
Nerhood 1994	0	1	0	2	3
Paul 1995a	1	2	2	1	6
Paul 1995b	2	2	2	1	7
Paul 1995c	1	2	2	1	6
Hasegawa 2001	2	2	2	1	7
Dainoff 2002	0	1	1	1	3
Roelofs 2002	1	1	2	2	6
Hedge and Ray 2004	2	2	1	1	6
Wilks 2005	2	1	1	1	5
Hedge 2005	2	2	2	1	7
Ebara 2008	1	1	2	1	5
Husemann 2009	2	2	2	1	7
Vink 2009	2	1	1	1	5
Davis 2009	2	2	2	2	8

3.3.2 Studies' findings

Sit-stand interventions and discomfort

Results from six of the seven identified studies meeting criteria #4 showed reduced trends in discomfort for sit-stand work when compared to sit only work. The only exception was a study by Ebara and colleagues (2008), who found an increase in discomfort for sit-stand. The study consisted of a three way comparison between: a normal sitting only condition, a 'high' sitting only condition, and a 'high' sit to stand condition. The study found trends of generally higher discomfort in the 'high' sit only and 'high' sit-stand when compared to the normal sitting only condition. Although the study found statistically significant increases in discomfort for 'high' sit-stand forearm and wrist/hand discomfort when compared to normal sitting only; the comparison is not a true indication of the differences between sit-stand and sitting only work since the seated position in the sit-stand condition was not the same as the position in sitting only. Of the remaining six included studies that reported trends of reduced discomfort, three studies found statistically significant decreases in worker discomfort when comparing sit-stand work to sitting only work (Hedge and Ray, 2004; Husemann et al., 2009; Vink et al., 2009). For the final three studies, either the decrease in worker discomfort reported was not significant or the statistical methods were not reported in enough detail to determine significance.

Sit-stand interventions and productivity

Results from three of the eight included studies meeting criteria #5 showed an increase in productivity for sit-stand work when compared to sit only (Dainoff, 2002; Hedge and Ray, 2005; Ebara et al., 2008). Four studies meeting criteria #5 showed no affect on productivity (Nerhood and Thompson, 1994; Hedge et al., 2005; Davis et al., 2009; Husemann et al., 2009), while the remaining study by Hasegawa and colleagues (2001) found a mixed result of a higher volume of work performed for sit-stand workers but lower quality of work.

Sit-stand interventions and other outcome measures

Three studies identified in this review primarily examined outcome measures other than discomfort or productivity. Paul and Helander (1995) measured spinal shrinkage and found that office workers that stood for 30 minutes every two hours, had significantly less spinal shrinkage than those that stood 15 minutes every hour. In another study, Paul (1995) found that average foot swelling in office workers with sit-stand furniture was significantly less than workers without sit-stand furniture. Finally, Hedge et al. (2005) measured wrist posture, and found that wrist posture changed between sitting and standing.

Study descriptions

A table summarizing details of each study under the headings: methods, participants, sit-stand paradigm, outcome measures, and additional notes were created. This table can be found in **Appendix A**.

3.4 DISCUSSION

3.4.1 Optimal sit-stand ratio

From this review of the literature, 12 of the 14 identified studies found at least some benefit to using a sit-stand work paradigm. However, one major limitation to implementing a sit-stand work paradigm in an office setting was the lack of an optimal ratio between time sitting and time standing being established. Paul (1995a, 1995b, 1995c) used a ratio of 3:1 sit versus standing to examine the effectiveness of the sit-stand paradigm on foot swelling, spinal shrinkage, or worker energy; dividing the day with either 15 minutes of standing every hour or 30 minutes every two hours, with no outcome measures concerning discomfort or productivity. Husemann and collegues (2008) used a 2:1 sit versus stand paradigm to look at discomfort and productivity over four-hour work periods, finding significantly lower discomfort and no change in productivity. With only one ratio used, results from this study cannot be used to extrapolate an optimal ratio to maximize the decrease in discomfort. Hasegawa and colleagues (2001) used a ratio of 1:1 sit versus standing. Hasegawa divided both 60 and 90-minute work blocks with combinations of 15, 30, or 45-minute sit or stand sub-blocks, finding a mixed result of increased workload and reduced productivity as a result. This result may be interpreted as a sit-stand ratio of 1:1 involved too frequent changes to standing postures, and the decrease in productivity as a result of such posture changes is not offset by the potential productivity increase from a reduction in discomfort.

In 2004, Hedge and Ray reported that when employees were given a sit-stand workstation, on average the employees increased the amount of time they spent standing while working, from 8.3% to 21.2% of their workday. This increase of 12.9% of the workday resulted in an average

27.5% decrease in musculoskeletal discomfort prevalence. This corresponds to about 8 additional minutes standing per hour.

With respect to discomfort and body region, Roelofs and Straker (2002) found lower limb discomfort was greatest in their standing only condition, with little difference found between sitting only and sit/stand. Their study used a sit/stand ratio of 1:1, alternating between sitting and standing every 30 minutes. Additional studies have shown a strong association between low back pain and standing occupations (Andersen et al., 2007; Roelen et al., 2008) or prolonged constrained standing work (Nelson-Wong and Callaghan, 2010). This suggests that if the standing portion of the sit-stand cycle is too long, there may be no reduction in discomfort resulting from sit-stand.

The diverging outcome measures used across each study reviewed prevents a clear conclusion to be drawn with respect to the optimal sit-stand time ratio. Perhaps no such optimal ratio exists, or if a ratio does exist, estimation of such involves an interaction with the type and distribution of the work being performed and the individual worker. Depending on the type of outcome the employer wishes to maximize (ex. reduced discomfort or increased productivity), there may be a different optimal sit-stand ratio. As such, employers should encourage their employees to experiment with various sit-stand time ratios in order to determine the optimal ratio for their specific personal and job requirements. A study by Alkhajah et al. reported that when office workers in Australia were given sit-stand workstation and minimal instructions, the workers chose an average sit-stand ration of 15 minutes sitting to 5 minutes standing.

3.4.2 Selection bias

Although an extensive search strategy was used to identify all studies on the topic of sit-stand workstations in an office setting, there is a possibility some studies may have been missed. While reference checking was employed in an attempt to trap any missed studies, there still exists the possibility that some relevant studies may not have contained the keywords used in the database searches or the studies appeared in publications not indexed in the databases used.

3.4.3 Discomfort versus Productivity

Since half of the studies identified concerning sit-stand work did not include any measure of discomfort, it appears as though injury prevention is not the sole motivation for researchers examining sit-stand workstations. Three studies did measure a biomechanical variable other than discomfort (Paul and Helander, 1995a; Paul, 1995b; Hedge et al., 2005) indicating injury prevention was a driving factor in those studies. However, the remaining four studies made no biomechanical, or ergonomic, measure whatsoever. Furthermore, of the seven included studies which did measure discomfort, four measured additional outcomes related to productivity (Nerhood and Thompson, 1994; Ebara et al., 2008; Husemann et al., 2009; Davis et al., 2009). Three of these studies found sit-stand had no affect on productivity, while one study found sit-stand was associated with increased productivity.

3.4.4 Injury Trade-offs

Sit-stand work is likely advantageous when considered in terms of reducing low back discomfort (Nerhood and Thompson, 1994; Roelofs and Straker, 2002; Hedge and Ray, 2004; Husemann et al., 2009; Vink et al., 2009; Davis et al., 2009). Conversely, there is evidence that alternating between sitting and standing may lead to higher wrist discomfort (Ebara et al., 2008). Most sit-stand workstations can be quickly and easily adjusted in height, however, do not have quick and easy to adjust keyboards and mouse pads for optimal wrist postures. Ideal wrist position while standing is different than ideal wrist position while sitting (Hedge et al., 2005). The study completed by Roelofs et al. (2002) found that greatest upper limb discomfort was found in the sitting posture. This is in contradiction with the arguments made by both Hedge (2005) and Dainoff (2002), resulting in an interesting quandary. Knowing that ideal wrist posture is different between sitting and standing, perhaps in the case of Roelofs (2002), less upper limb discomfort was experienced while standing because the workstation was better adjusted for wrist posture while standing rather than sitting. However, this is purely speculative as none of the workstations' configuration descriptions provided were sufficient to assess this hypothesis.

3.4.5 Worker Productivity

Productivity can be measured in a number of different ways. In terms of total volume of work and quality of work accomplished, Husemann et al. (2009) found a small but not significant decrease in number of keystrokes and a small but not significant increase in error rate between sit-stand and sit only. This result of either little or no decrease in productivity measures was found quite consistently across all included studies (Hasegawa et al., 2001; Hedge et al., 2005;

Ebara et al., 2008). At this point, it is important to note that although this evidence does suggest sit-stand resulted in little or no decrease in productivity in a lab setting, the way in which these laboratory results will transfer into industry is still unknown. Though efforts were made in all studies to best simulate real industry work, many of the well-known limitations of laboratory work still exist.

From another perspective, Dainoff (2002) suggested that implementing a sit-stand protocol could create greater worker productivity by decreasing the break time a worker will take if using a sit-stand paradigm. Somewhat contrary to this idea, Nerhood and Thompson (1994) found when tracking absenteeism for a 6-month period, no significant difference between sit-stand workstation users and sit only workstation users. While a small number of studies have examined productivity related issues in sit-stand stations, none have found a definitive detrimental impact of using sit-stand workstations when compared to seated work. None of the identified studies reported outcome measures related to experience, communication, or creativity. Further research is needed including these outcome measures as sit-stand workstations can change an office environment, and some literature has shown that the office environment can have an effect on creativity (Ceylan et al., 2008).

3.4.6 Sit-stand Workstation Implementation and Utilization

Cost is likely a contributing factor when considering whether or not to implement sit-stand workstations in an office environment. Height adjustable desks capable of supporting a sit-stand paradigm can range in price from approximately US$500 - $2000 (www.ergodepot.com). A reduced worksurface area, when compared to fixed height workstations, has also been previously associated with sit-stand workstations (Wilks et al. 2006). This reduced worksurface area may not meet the requirements for certain occupational groups (Grunseit et al. 2013).

Height adjustable workstations are considered more flexible than fixed height workstations (Wilks et al. 2006). This increased flexibility may allow for one desk to be shared by several different persons; therefore, reducing the total number of desks required in an office. Fewer desks can result in both purchase cost savings and reduced floor space requirements.

Utilization is another factor likely considered in the decision to implement sit-stand workstations. Although literature dating back to the 1990s has shown the potential positive effects of the sit-stand paradigm (Nerhood and Thompson, 1994), a study from 2006 found that as few as one in ten workers actually use the sit-stand feature of their workstation on a daily basis (Wilks et al., 2006). From their study, Wilks and colleagues developed a series of recommendations to improve the implementation of sit-stand workstations. These recommendations included: consider different personnel groups' differing needs for table area; and be conscious that the correct use of sit-stand workstations requires education and motivation.

Wilks also found that if a worker either constantly or intermittently experienced pain while working, that worker was more than twice as likely than a worker whom experiences no pain, to use the sit-stand feature at least once a day. Instruction also appeared to be a factor, with workers that received instruction from either a physiotherapist or ergonomist being nearly twice as likely to use the sit-stand feature at least once a day. This further highlights the need for proper education and motivation to ensure the successful implementation and utilization of sit-stand workstations.

3.5 CONCLUSIONS

The majority of the current literature surrounding sit-stand workstations indicates implementing such a system in an office environment will lead to lower levels of reported whole body discomfort among employees, without resulting in a significant decrease in performance. There is also sufficient evidence to conclude sit-stand workstations are effective in reducing local discomfort reported in the low back.

From the performed review, there are two areas with little definitive information that exist in the sit-stand literature. First, even though it appears that sit-stand workstations can effectively reduce whole body and low back discomfort, some evidence suggests sit-stand workstations can increase reported discomfort in the upper extremities (specifically hand and wrist). Further research exploring changes in whole body posture during sitting and standing work are needed to assess this potential confounding negative outcome. Second, there are no generally agreed upon usage ratios for time spent between standing and sitting at workstations. A number of different ratios have been used in sit-stand workplace/laboratory interventions, with little or no justification given. Although the majority of ratios have shown positive results, differences in outcome measures reported do not allow for a comparison between ratios. Further research exploring an optimal suggested sit-stand ratio would be beneficial in guiding usage guidelines and training.

Chapter 4 - A comparison of lumbar spine kinematics and kinetics during simulated sit-stand office work with prolonged sitting and prolonged standing office work

4.1 INTRODUCTION

Prolonged sitting while performing office work has been linked with low back discomfort (Fenety and Walker 2002; Frymoyer et al. 1980; Magora 1972) even in people with no prior history of back pain (Beach et al. 2005). Low back postural adaptations to accommodate seated postures have long been suspected as the cause of low back pain (Majeske and Buchanan 1984). In sitting, the lumbar spine is flexed relative to standing and this prolonged postural exposure has been shown to increase intra-discal pressures, and viscoelastic creep in passive elements using in-vitro cadaveric motion segments (Adams and Dolan 2005). Prolonged seated exposure has been hypothesized to lead to chronic low back injuries such as disc herniation (Kelsey 1975, Videman et al. 1990).

An obvious alternative to sitting is standing. Unfortunately, studies have also shown a strong association between low back pain and standing occupations (Andersen et al. 2007; Roelen et al. 2008). Further, a review by Claus et al. (2008) concluded that intra-discal pressures during standing is often similar intra-discal pressures during sitting, and sitting is not worse than standing for disc degeneration or low back pain incidence. Given that there may be negative outcomes, specifically pain, associated with both sitting and standing, sit-stand workstations may be a suitable compromise.

A sit-stand workstation is defined as a workstation that allows a user to perform the same tasks from either a seated or standing posture. These workstations allow the work surface height to be adjusted quickly and safely with minimal disruption in task performance. Thus, the theory underlying the sit-stand work paradigm consists of a worker performing their duties while periodically alternating between sitting and standing throughout the day to introduce postural variation. Sit-stand workstations are becoming more common in the workplace with a growing number of employers implementing them when workstations are added or replaced. However, from a usability standpoint, a study surveying four companies in Europe that converted to sit-stand workstations showed that only about one in five employees use the sit-stand feature at least once a day (Wilks, Mortimer, and Nylen 2006).

There exists a small body of literature demonstrating potential benefits of sit-stand work in the field (Nerhood and Thompson 1994; Hedge and Ray 2004; Vink et al. 2009); however, due to logistical limitations there is a lack of robust controls in these studies. Each field study referenced involved the distribution of an initial survey asking questions concerning: types of tasks performed while working, time spent sitting, and regional discomfort. The intervention of a new sit-stand workstation accompanied by some form of instruction was then followed by a second questionnaire asking either the same or similar questions as the initial survey. Each of the field studies has reported promising results with respect to the potential of sit-stand workstations to reduce regional discomfort, although much more work still needs to be done to understand the basic principles as to why sit-stand work may be beneficial, and to optimize the effectiveness of the sit-stand work paradigm.

4.2 PURPOSE

The purpose of this study was to investigate the effect of a sit-stand office workstation on trunk and lumbar postures, lumbar spine loading, whole back discomfort, and task productivity compared to traditional seated and standing configurations in a laboratory setting for typical workplace tasks (typing, reading, data entry). Specifically, a one-hour sit-stand (15 minutes sitting to 5 minute standing ratio) protocol was compared to a one-hour sit only protocol and a one-hour stand only protocol.

Trunk and lumbar spine postures (flexion/extension); lumbar spine loading (compressive and shear force); whole back discomfort (visual analogue scale); and productivity criteria (total keystrokes/mousing problems, correct keystrokes/mousing problems, and keystroke/mousing problem error rates) were compared between sitting, standing, and sit-stand work to determine if there were differences between these dependent variables across conditions.

4.3 HYPOTHESES

There were three main hypotheses for this study:

1) Sit-stand work will positively influence both seated and standing lumbar spine mechanics when compared to either posture performed in isolation.

   Rationale: Lumbar spine flexion has been shown to increase during prolonged sitting (Sanchez-Zuriaga et al. 2010) and prolonged standing (Gregory and Callaghan 2008a), potentially as a result of tissue creep. Intermittent bouts of standing between sitting periods may reduce the potential effects of tissue creep on lumbar spine posture.

2) Sit-stand work will reduce low back discomfort when compared to either posture performed in isolation.

   Rationale: Altered mechanical loading, due to creep in the passive structures in the lumbar spine, has been suggested as a possible cause of discomfort during static postures (Gregory and Callaghan 2008a). Altering postural exposures between sitting and standing, in an attempt to reduce potential tissue creep, may result in less discomfort.

3) Sit-stand work will not reduce productivity when compared to either posture performed in isolation.

   Rationale: The positive effects of reduced discomfort will balance the adverse effects of switching postures on performance.

4.4 METHODS

4.4.1 Participants

Twenty-four participants (12 male and 12 female) were recruited from the university population (**Table 4-1**). Participants were excluded if they: (1) had experienced an episode of severe non-specific low back pain within the last six months that had caused them to miss at least one day of school or work; (2) had back pain at the time of the study; (3) self identified as developing low back pain from sitting that would lead them to avoid prolonged seated exposures (i.e. long drive); (4) held a job that involved prolonged standing exposures for more than 10 hours a week; or (5) had upper extremity pain that limited their ability to perform typing/mousing tasks.

Table 4-1: Participant Statistics

	Age (years)	Height (m)	Body Mass (Kg)
Male (n = 12)	22.63 ± 1.69	1.79 ± 0.09	77.56 ± 14.56
Female (n = 12)	23.78 ± 3.03	1.65 ± 0.05	61.46 ± 7.99

4.4.2 Procedures

Participants took part in a three-hour data collection that consisted of three blocks (one hour each) of seated work, standing work, and sit-stand work in a balanced randomized presentation order. The sit-stand work was cycled as follows: 15 minutes of seated work with 5 minutes of standing work. The three to one ratio for seated to standing exposures was chosen to be consistent with previous work that showed a beneficial response to 3:1 sit-stand work cycling

(Paul 1995; Paul and Helander 1995). Please refer to **Figure 4-1** for a schematic depicting the complete study procedure.

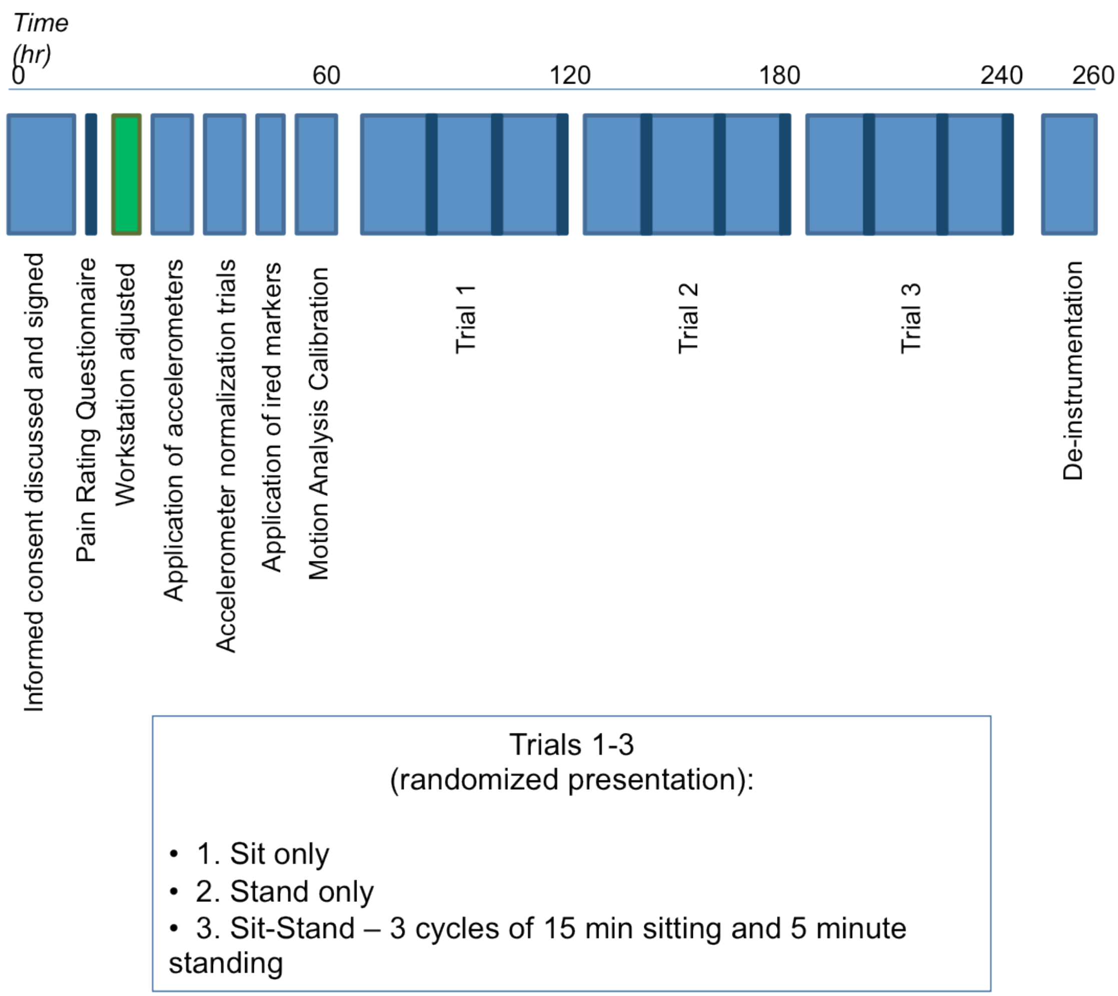


Figure 4-1 - Data collection timeline

Office work consisted of standardized data entry tasks (both typing and mousing). For the typing task, a graphical user interface (GUI) was split in two fields (**Figure 4-2**). One field consisted of a body of text and the other was an empty field for the participant to re-type the given body of text. For the mousing tasks, the participant was presented with simple arithmetic problems through the GUI and were required to provide the correct answer by clicking the appropriate locations on a number pad, also appearing on the GUI (**Figure 4-3**). The customized software for the typing/mousing tasks were created using Matlab R2011a (The Mathworks Inc., Natick, Massachusetts, USA). The tasks alternated between short 50-second blocks of typing and mousing throughout the three-hour protocol. Each short typing task was designed to take much longer than the allocated 50 seconds to complete, even for the most skilled typist. Arithmetic problems for the mousing task were created using a random number generator, and therefore the supply of problems was endless and the difficulty was sufficiently randomized. An attempt was made to ensure difficulty of typing tasks were constant. Even so, typing tasks were also presented in a randomized order.

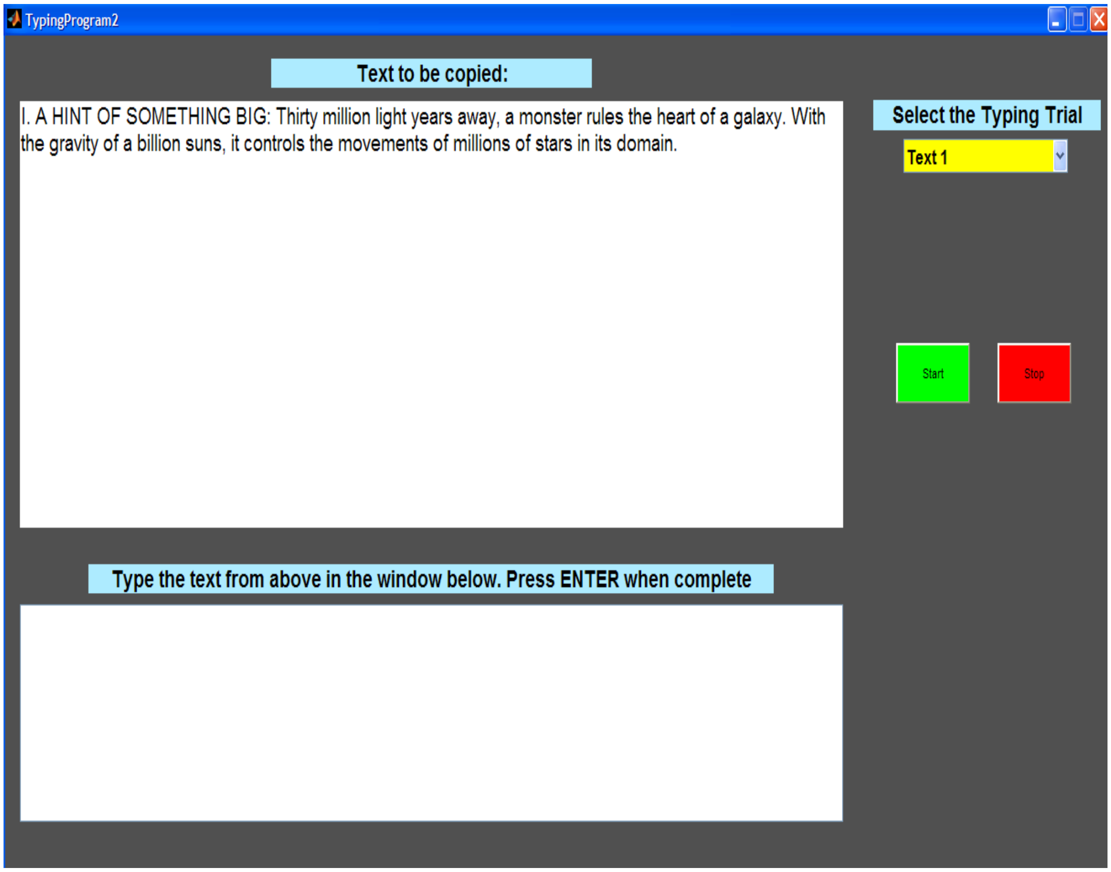


Figure 4-2 - Typing task GUI

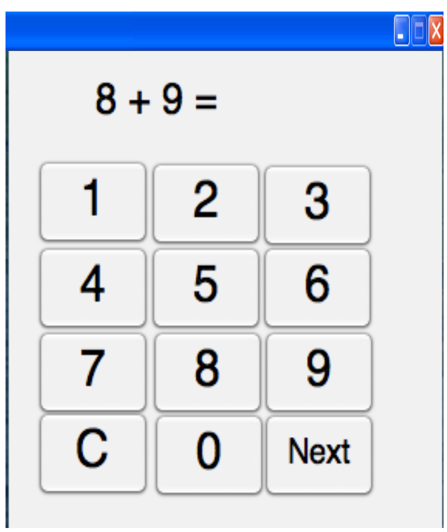


Figure 4-3 – Mousing task GUI

The sit-stand workstation used was a counterbalance height adjustable table (Teknion Xpres, Teknion Corp, Toronto, ON; **Figure 4-4**) with a work surface adjustable height range between 68 cm - 114 cm (~27" - 45"). The chair used was a standard office chair (Borgo Gendra, Borgo Contract Seating, Toronto, ON) with the back support and armrests removed in order to prevent motion capture marker occlusion. Participants were introduced to the equipment (work table, chair etc.) to be used in the study. Table/chair heights for both seated and standing work were adjusted during this introduction time. Each participant was fitted to the workstation such that at the initiation of the sitting work trial, elbow, hip, and knee angles were at 90 degrees. For each block of standing work, the experimenter raised the workstation to a height that accommodated light standing work, with the work surface just below elbow height (NIOSH 1997). The participant was also given time to become familiar with the customized data entry software program. The customized software presented the typing and mousing tasks; tracked productivity measures; cued sit-stand cycles; and presented surveys for rating of perceived discomfort throughout the experiment.

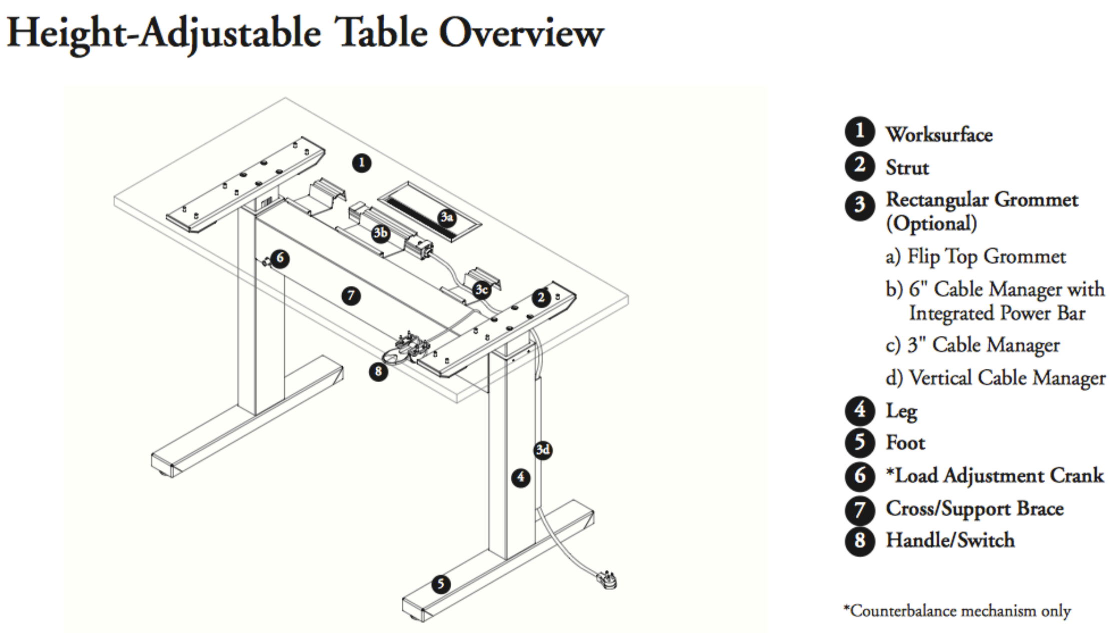


Figure 4-4 - Schematic of Teknion Xpress - Height Adjustable Table. Modified from: http://www.teknion.ca/pricing/complements/pdfs/complements.pdf

4.4.3 Dependent Measures

Posture - Whole body posture was captured in three dimensions using an optoelectronic system (Optotrak, Northern Digital Inc., Waterloo, Ontario, Canada) at a sample rate of 32 Hz. The three-hour testing session was divided into nine 20-minute blocks, each further divided into 5-minute 'trials'. Markers were affixed to rigid braces to form technical marker clusters, with six markers on each brace. The braces were then attached to 13 body segments: two feet, two legs, two thighs, two upper arms, two forearms, pelvis, trunk, and head/neck (**Figure 4-5**). Markers were also affixed to the chair in order to track the position of the occupant with respect to the chair, throughout the testing session. A five-second upright standing and five-second maximum flexion trial were collected prior to the three-hour testing to determine lumbar spine range of motion. Trunk and lumbar angles were calculated from three tri-axial accelerometers, affixed with double sided tape over the following landmarks: spinous processes of C7, L1 and S1. Accelerometer data were collected simultaneously with motion capture data, analogue low-pass filtered at 50 Hz, A/D converted using a 16-bit board at a sampling frequency of 256 Hz, and divided into 5-minute trials. A second custom software program (Matlab R2011a, The Mathworks Inc., Natick, Massachusetts, USA) was used to process the data as follows: calibrate all three axis with respect to gravity, smooth the data using a 2^{nd} order Butterworth filter with a 1 Hz cut off frequency (Dunk and Callaghan 2010).

Figure 4-5 - Mockup of participant standing while completing a discomfort questionnaire. Note: Although an active marker motion capture system was used, for this mockup, markers are not daisy chained together for power as they would be for a real data collection.

L4-L5 Loading – A 3D rigid link segment model (LSM) was created to estimate L4-L5 reaction forces using posture data, force data, and anthropometric data based on measured segment lengths and whole body mass (Winter 1990). The LSM was similar to LSMs previously described (Kingma 1996; Abdoli-Eramaki 2009). For each 5-minute standing trial, participants were positioned on two force plates, allowing the ground reaction forces at the left and right foot to be measured separately. Each force plate was sampled at 1024 Hz, dual passed through a 2nd order Butterworth low pass filter with an effective cutoff frequency of 16 Hz, and then down sampled to 32 Hz to match the posture data. For each 5-minute sitting trial, the participant's feet were again positioned on the two force plates (Advanced Medical Technologies Inc., Newtown, MA, USA), and a 1296 channel pressure sensor (Xsensor3 Seating System, XSensor Technology Corporation, Calgary, Alberta, Canada) was placed between the participant and the seat pan. Relative position between the pressure sensor and seat pan remained constant, therefore motion tracking of the seat pan also provided the position and orientation of the pressure sensor in space. The pressure sensor was sampled at 32 Hz. The foot base of the chair was placed entirely on a third force plate to measure the reaction kinetics on the seat. The seat reaction force was then applied to the LSM at the center of pressure (CoP) location, calculated from the pressure sensor data and transformed into the global coordinate system. Force measured using the force plates under the two feet were again applied to the LSM as ground reaction forces on the feet at the respective CoP locations. Muscle contribution to joint loading was determined using a methodology previously described (Gregory 2005). A single resultant muscle force was calculated to balance the moments in the sagittal plane about the L4-L5 joint using an assumed 6 cm moment arm, and a line of a action 5.3 degrees in the posterior direction for the extensors

(McGill and Norman 1987) and 4.5 cm moment arm with a line of action parallel to the joint axis for the flexors (McGill et al. 1996).

Shifts, drifts and fidgets – Shifts, drifts, and fidgets were counted throughout each one-hour trial (sit only, stand only, and sit-stand) using the C7 accelerometer data and a custom written Matlab program. Shifts, drifts, and fidgets were determined using a hybrid of methods similar to that previously described (Duarte and Zatsiorsky 1999; Dunk and Callaghan 2010). Shifts were defined as a fast, step-like change in the position/orientation of the accelerometer affixed to the skin above C7. More specifically, accelerometer data was averaged over 3-second epochs throughout each trial. A shift was defined as: any point in the trial where two consecutive epochs (n and n+1) had a difference in flexion/extension angle or lateral bend angle of greater than 5 degrees and the third consecutive epoch (n+2) did not return to within 1 degree of the first epoch (n). A fidget was similar to a shift, except for a fidget the orientation of the accelerometer returned to approximately the same position as before the shift. The threshold for 'approximately the same position' was defined as within 1 degree in both the flexion/extension and lateral bend directions. A drift was a slow continuous change in orientation of the C7 accelerometer. Specifically, this was defined as: any point within the trial where over 3 or more consecutive epochs flexion/extension angle or lateral bend angle changed by greater than 5 degrees, but not including changes of 5 degrees or greater that occurred during consecutive epochs (ie. not including shifts).

Discomfort - Perceived ratings of discomfort were measured by visual analogue scale throughout the study at 5-minute intervals when prompted by the customized Matlab GUI. Participants rated their discomfort for neck, 4 areas of the back (bilateral upper back and lower back), bilateral buttocks and thighs on a 100 mm continuous line with the following anchors: 0 = no discomfort and 100 = extreme discomfort (**Figure 4-6**). Data were calculated from these questionnaires by determining the distance from 0 to the mark indicated by the participant to the nearest mm within the customized software program. To remove bias from any low level pain participants might be experiencing on the testing day, baseline responses from the start of each testing condition were removed from each subsequent questionnaire. Whole back discomfort was calculated as a summation of the four areas of the back. The decision to calculate whole back discomfort was made based on pilot data showing that the location of reported back discomfort varied greatly between individuals, leading to data with a high level of variability. When all areas of the back were summated, the level of variability in the data was considerably reduced. Although still slightly different than previous methods used to report low back discomfort, whole back discomfort metric is a more similar method to methods previously reported in the literature (Gallagher et al. 2014) compared to the regional method shown in **Figure 4-6**.

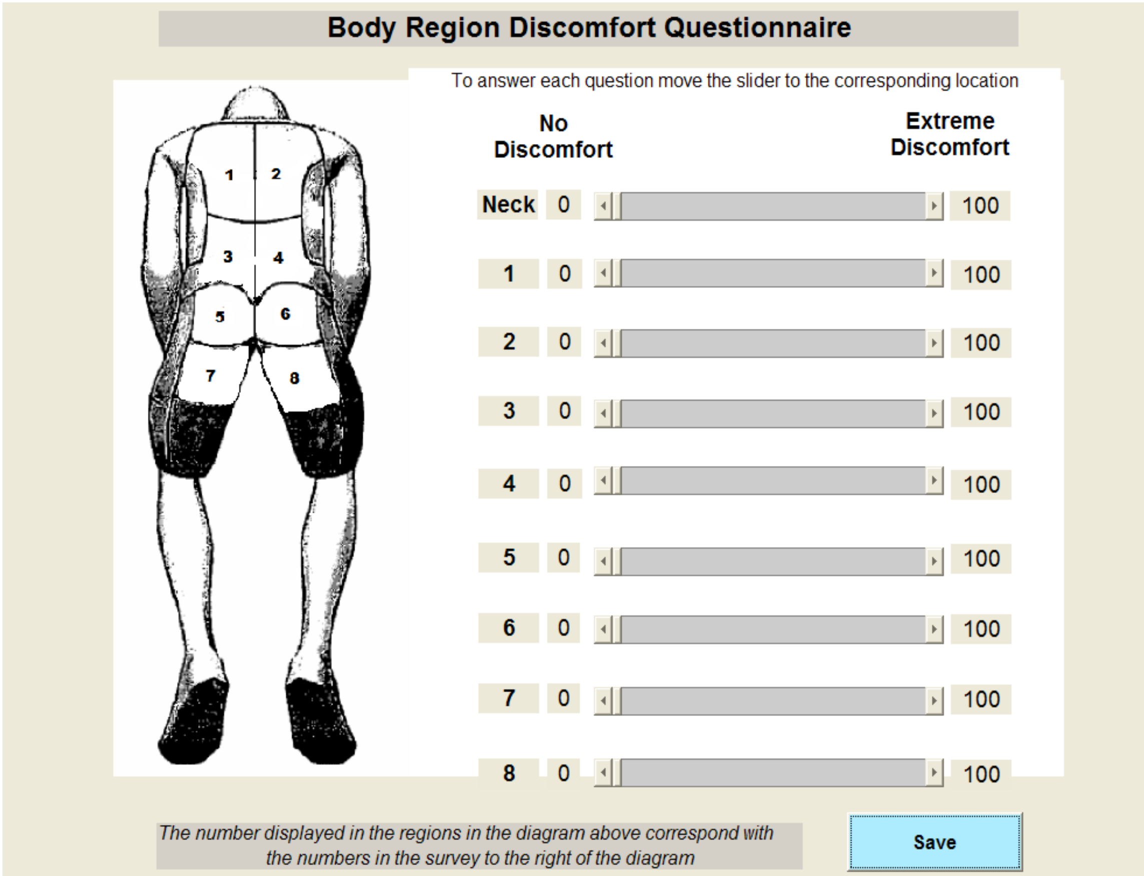


Figure 4-6 – Discomfort questionnaire GUI.

Productivity - The customized typing/mousing task software monitored total keystrokes/mousing problems, correct keystrokes/mousing problems, total errors and error rate as measures of productivity throughout the study. All productivity measures were reported as per minute averages for each of the three testing conditions.

4.4.4 Statistical Analysis

Statistical approach differed depending on the outcome variable being tested. In total, three different statistical approaches were utilized.

The first approach was a two-way mixed general linear model with gender as a between factor and workstation type as a within or repeated factor. This model was used to compare outcome measures: average keystrokes, average correct keystrokes, average mousing problems attempted, average correct mousing problems completed.

The second approach compared across all three trial conditions with shifts, drifts, fidgets, and discomfort as dependent measures. A three-way mixed general linear model was utilized with gender as a between factor and workstation type and time as within factors. Time increments used for shifts, drifts, and fidgets were 20-minute blocks, whereas time increments for discomfort were 5-minute trials. Statistical significance was accepted at the p=0.05 level and Tukey post hoc testing was completed as required.

For the third approach, the sitting component and the standing component were analyzed separately in the sit-stand protocol. Five-minute trials between minutes 10-15, 30-35, and 50-55 of the sit-stand protocol were compared with the equivalent trials for the sit only protocol, and five-minute trials between minutes 15-20, 35-40, and 55-60 of the sit-stand protocol were compared with the equivalent trials in the stand only protocol. For the sitting component, the dependent variables: average posture and average L4-L5 loads were compared between workstation configuration (seated only and sit-stand) using a three-way mixed general linear model with gender as a between factor and workstation type and time as within factors. Statistical significance was accepted at the $p=0.05$ level and post-hoc pairwise testing was completed as required. An equivalent statistical analysis was completed for the standing component, with the dependent measures being compared between standing only and sit-stand configurations.

4.5 RESULTS

This section is divided into five sub-sections. Each sub-section focuses on one of the five types of dependent variables from this study: Discomfort, Posture, Loading, Productivity, and Shifts, Drifts and Fidgets.

4.5.1 Discomfort

Over time, whole back discomfort demonstrated a rising trend for both the prolonged sitting and standing conditions (**Figure 4-7**). Gender, workstation, and time were all found to be statistically significant factors ($p = 0.006$, $p = 0.006$, and $p = 0.043$ respectively; **Table 4-2**). Generally speaking, males perceived higher levels of discomfort than females, discomfort was lower in the sit-stand workstation type compared to either sit only or stand only, and discomfort increased over time. A complete post-hoc analysis can be found in **APPENDIX B**. An interaction between gender and workstation type was also found ($p = 0.004$). No other interactions were found. The sit-stand workstation type showed distinct periods of 'recovery' at time intervals 20, 40, and 60 minutes (**Figure 4-7**). These 'recovery' periods coincide directly with the transition periods between sitting and standing at 15-20, 35-40, and 55-60 minutes.

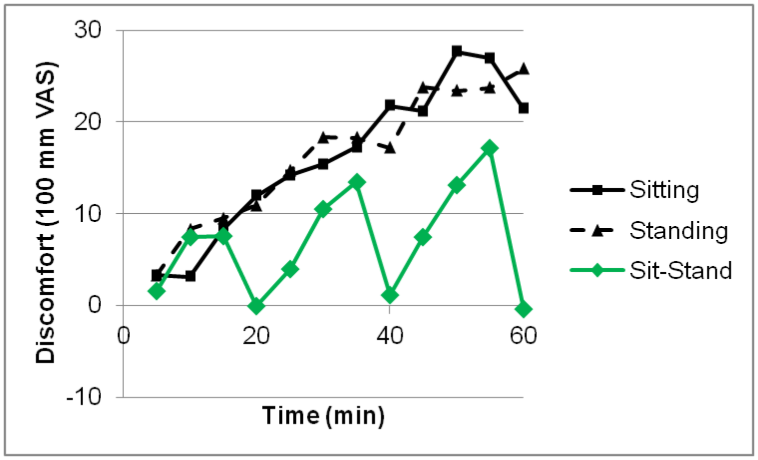


Figure 4-7 - Whole back discomfort over time; presented as a summation of all the regions of the back presented on the discomfort questionnaire. This graph includes male and female data collapsed together. *Note: Error bars are purposely not included on this graph due to the number of data points. Please see Table 4-2 for an idea of the variability in this data.

Table 4-2: Discomfort descriptive statistics (mean and standard deviations) and inferential statistics (3-Way ANOVA)

Males

Time (min)	Sit (mm)	Stand (mm)	Sit-Stand (mm)
5	4 ± 17	3 ± 9	5 ± 11
10	3 ± 7	10 ± 16	14 ± 36
15	11 ± 17	14 ± 17	12 ± 23
20	12 ± 15	18 ± 28	10 ± 29
25	15 ± 25	25 ± 34	15 ± 46
30	13 ± 19	27 ± 41	21 ± 41
35	10 ± 26	26 ± 36	24 ± 41
40	17 ± 27	25 ± 33	13 ± 38
45	17 ± 37	34 ± 42	17 ± 36
50	16 ± 39	33 ± 41	21 ± 45
55	13 ± 48	32 ± 37	24 ± 39
60	13 ± 46	34 ± 43	9 ± 24

Females

Time (min)	Sit (mm)	Stand (mm)	Sit-Stand (mm)
5	3 ± 9	4 ±12	-1 ± 6
10	3 ± 8	7 ± 18	2 ± 14
15	6 ± 12	6 ± 23	4 ± 17
20	12 ± 20	5 ± 20	-9 ± 30
25	13 ± 28	6 ± 24	-6 ± 16
30	17 ± 39	11 ± 40	2 ± 11
35	23 ± 53	12 ± 36	5 ± 21
40	26 ± 56	10 ± 36	-9 ± 25
45	24 ± 68	15 ± 43	-1 ± 10
50	38 ± 77	16 ±48	7 ± 24
55	38 ± 81	17 ± 54	12 ± 34
60	28 ± 77	19 ± 48	-8 ± 33

ANOVA

	p
Gender x Workstation x Time	0.9999
Gender x Workstation	0.0004
Gender x Time	0.9976
Workstation x Time	0.9981
Gender	0.0063
Workstation	0.0056
Time	0.0434

4.5.2 Posture

Lumbar flexion angle was consistently greater during prolonged sitting when compared to prolonged standing (**Figure 4-8**). During equivalent sitting bouts, lumbar flexion was significantly higher in the sitting only workstation type when compared to the sit-stand workstation ($p = 0.038$). While standing, lumbar flexion angle was consistently negative, with a negative angle representing relative extension compared to quiet standing. When flexion angle was broken down by gender, only males were found to consistently average an extended posture during standing (**Table 4-3**). The gender factor was significant ($p = 0.0117$; **Table 4-4**).

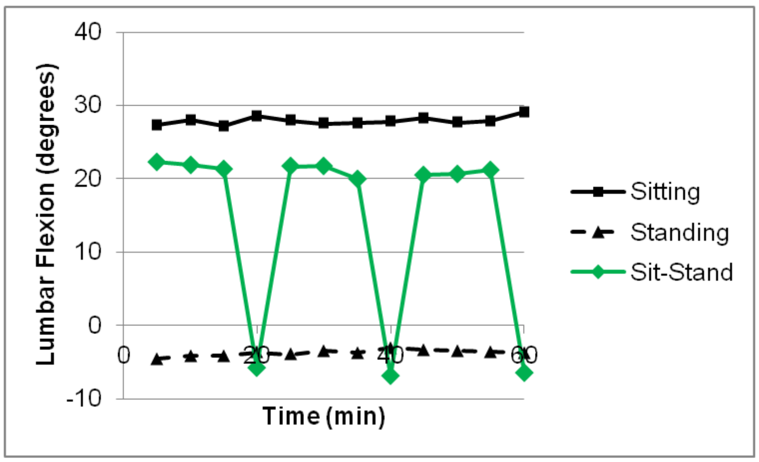


Figure 4-8 - Lumbar spine posture over time. Positive angle values represent lumbar spine flexion from neutral (as defined by quiet standing). *Note: Error bars are purposely not included on this graph due to the number of data points. Please see Table 4-3 for an idea of the variability in this data.

Table 4-3: Lumbar Angles – Sit versus Sitting during Sit-Stand

Males

Time (min)	Sit (degrees)	Sit-Stand (degrees)
10-15	25.13 ± 14.36	20.34 ± 17.64
30-35	27.41 ± 13.99	18.30 ± 19.95
50-55	27.05 ± 13.99	19.82 ± 20.09

Females

Time (min)	Sit (degrees)	Sit-Stand (degrees)
10-15	29.83 ± 8.79	22.53 ± 18.82
30-35	27.84 ± 8.89	22.08 ± 21.38
50-55	28.84 ± 7.80	22.98 ± 21.31

ANOVA

	p
Gender x Workstation x Time	0.9292
Gender x Workstation	0.9082
Gender x Time	0.9843
Workstation x Time	0.9837
Gender	0.4012
Workstation	0.038
Time	0.9797

Lumbar extension during the standing portion of sit-stand was also found to be consistently greater than extension during prolonged standing, indicated by a more negative value (**Figure 4-8**); however, this trend was not found to be significant (p = 0.357; **Table 4-4**).

Table 4-4: Lumbar Angles – Stand versus Standing Sit-Stand

Males

Time (min)	Stand (degrees)	Sit-Stand (degrees)
15-20	-7.29 ± 13.33	-8.70 ± 16.75
35-40	-6.78 ± 13.62	-10.70 ± 19.94
55-60	-7.21 ± 14.54	-10.09 ± 20.66

Females

Time (min)	Stand (degrees)	Sit-Stand (degrees)
15-20	0.89 ± 14.95	-2.06 ± 14.88
35-40	1.69 ± 14.84	-2.00 ± 15.26
55-60	0.59 ± 15.80	-1.85 ± 15.59

ANOVA

	p
Gender x Workstation x Time	0.9899
Gender x Workstation	0.9628
Gender x Time	0.9882
Workstation x Time	0.9764
Gender	0.0117
Workstation	0.357
Time	0.9957

No significant differences were found for trunk angle when comparing equivalent time periods for sit only and sitting phases of the sit-stand workstation type (**Table 4-5**). When comparing stand only to the stand component of the sit-stand rotation, a significant difference gender difference was found ($p = 0.0016$; **Table 4-6**). Again, males stood with a more extended posture. No other significant differences were found (**Table 4-6**).

Table 4-5: Trunk Angles – Sit versus Sitting during Sit-Stand

Males

Time (min)	Sit (degrees)	Sit-Stand (degrees)
10-15	22.40 ± 21.08	24.16 ± 18.36
30-35	22.69 ± 23.85	22.04 ± 20.77
50-55	24.50 ± 24.25	23.34 ± 21.47

Females

Time (min)	Sit (degrees)	Sit-Stand (degrees)
10-15	23.25 ± 23.68	20.31 ± 21.08
30-35	20.81 ± 23.17	21.09 ± 22.83
50-55	22.33 ± 23.46	22.39 ± 23.99

ANOVA

	p
Gender x Workstation x Time	0.9515
Gender x Workstation	0.9218
Gender x Time	0.9999
Workstation x Time	0.9991
Gender	0.731
Workstation	0.9187
Time	0.9613

Table 4-6: Trunk Angles – Stand versus Standing during Sit-Stand

Males

Time (min)	Stand (degrees)	Sit-Stand (degrees)
15-20	-1.94 ± 11.87	-2.55 ± 14.29
35-40	-1.87 ± 11.75	-4.37 ± 17.18
55-60	-1.47 ± 13.47	-4.96 ± 17.44

Females

Time (min)	Stand (degrees)	Sit-Stand (degrees)
15-20	8.23 ± 15.64	4.63 ± 14.99
35-40	8.71 ± 16.07	5.05 ± 15.62
55-60	8.23 ± 16.23	4.70 ± 15.38

ANOVA

	P
Gender x Workstation x Time	0.9785
Gender x Workstation	0.8113
Gender x Time	0.9815
Workstation x Time	0.9798
Gender	0.0016
Workstation	0.3212
Time	0.9913

4.5.3 Loading

For L4/L5 compression during equivalent periods of sitting during the sit only and sit-stand workstation types, compression was found to be consistently higher in the sit-stand condition (**Table 4-7**). However, this difference was not found to be significant ($p = 0.7947$). A significant difference in compressive loading was found between males and females ($p<0.0005$), with males experiencing higher compressive loading in the L4/L5 joint.

Table 4-7: L4/L5 Compression – Sit versus Sitting during Sit-Stand

Males

Time (min)	Sit (N)	Sit-Stand (N)
10-15	507.67 ± 66.69	517.91 ± 79.48
30-35	507.50 ± 76.40	519.06 ± 80.99
50-55	510.98 ± 77.48	514.58 ± 79.97

Females

Time (min)	Sit (N)	Sit-Stand (N)
10-15	385.47 ± 165.36	389.77 ± 168.95
30-35	388.41 ± 168.62	393.26 ± 169.36
50-55	384.09 ± 173.58	387.58 ± 165.40

ANOVA

	p
Gender x Workstation x Time	0.9982
Gender x Workstation	0.9305
Gender x Time	0.9971
Workstation x Time	0.9966
Gender	<0.0005
Workstation	0.7947
Time	0.9956

When comparing compression between the equivalent standing time periods for the stand only and sit-stand workstation types (**Table 4-8**), there was no significant effect of workstation type or time (p = 0.4547 and p = 0.6703, respectively). The only significant effect was that of gender (p = 0.0002), with males generally experiencing higher compressive loads.

Table 4-8: L4/L5 Compression – Stand versus Standing during Sit-Stand

Males

Time (min)	Stand (N)	Sit-Stand (N)
15-20	534.74 ± 146.58	535.87 ± 142.25
35-40	580.36 ± 128.15	554.35 ± 131.20
55-60	558.03 ± 119.06	549.54 ± 159.09

Females

Time (min)	Stand (N)	Sit-Stand (N)
15-20	460.47 ± 163.22	420.25 ± 130.42
35-40	453.80 ± 107.13	453.30 ± 92.74
55-60	492.38 ± 89.33	452.51 ± 122.10

ANOVA

	p
Gender x Workstation x Time	0.8445
Gender x Workstation	0.7565
Gender x Time	0.871
Workstation x Time	0.9845
Gender	0.0002
Workstation	0.4547
Time	0.6703

In the A-P shear direction, a trend emerged showing consistently higher joint shear while sitting at the sit only workstation as compared to the sit-stand workstation (**Table 4-9**); however, this trend was not found to be statistically significantly (p = 0.0963). Males also experienced higher levels of shear on average; however, this trend was also not significant (p = 0.0765).

Table 4-9: L4/L5 Shear – Sit versus Sitting during Sit-Stand

Males

Time (min)	Sit (N)	Sit-Stand (N)
10-15	114.67 ± 65.08	98.30 ± 82.98
30-35	123.63 ± 61.28	89.18 ± 91.38
50-55	122.86 ± 63.15	95.17 ± 91.20

Females

Time (min)	Sit (N)	Sit-Stand (N)
10-15	96.00 ± 49.53	73.11 ± 79.89
30-35	89.65 ± 47.50	69.15 ± 84.66
50-55	92.25 ± 52.29	71.27 ± 82.91

ANOVA

	p
Gender x Workstation x Time	0.9564
Gender x Workstation	0.8685
Gender x Time	0.9851
Workstation x Time	0.9745
Gender	0.0765
Workstation	0.0963
Time	0.9857

When comparing A-P shear between standing in the stand only workstation type and standing in the sit-stand workstation type, shear was higher on average during sit-stand (**Table 4-10**); however, this trend was not significant (p = 0.4244). Males on average experienced higher levels of shear as well (p = 0.0573). It must also be noted that the magnitude of shear force was approximately five times lower while standing when compared to sitting (**Table 4-9** v. **Table 4-10**).

Table 4-10: L4/L5 Shear – Stand versus Standing during Sit-Stand

Males

Time (min)	Stand (N)	Sit-Stand (N)
15-20	-23.72 ± 56.01	-32.13 ± 71.50
35-40	-26.30 ± 65.11	-41.51 ± 85.51
55-60	-26.96 ± 65.53	-35.46 ± 82.58

Females

Time (min)	Stand (N)	Sit-Stand (N)
15-20	-2.97 ± 55.59	-12.09 ± 53.46
35-40	-1.71 ± 52.93	-12.60 ± 55.70
55-60	-1.46 ± 61.06	-9.92 ± 51.15

ANOVA

	p
Gender x Workstation x Time	0.9961
Gender x Workstation	0.9613
Gender x Time	0.9764
Workstation x Time	0.9864
Gender	0.0573
Workstation	0.4244
Time	0.9823

4.5.4 Productivity

Total key strokes and correct key strokes were slightly higher for both the prolonged sitting and prolonged standing workstation types when compared to sit-stand (**Figure 4-9**), but this difference was not found to be statistically significant (**Table 4-11**). The reverse trend was noticed for the mousing task (**Figure 4-10**). Total problems attempted and correct problems completed were slightly higher during sit-stand, but again this difference was not found to be significant (**Table 4-12**). Error rates for typing were as follows: prolonged sitting = 7.4 %, prolonged standing = 7.0 %, and sit-stand = 7.2 %. Error rates for mousing were as follows: sitting = 2.6 %, standing = 2.5 %, and sit-stand = 2.7 %.

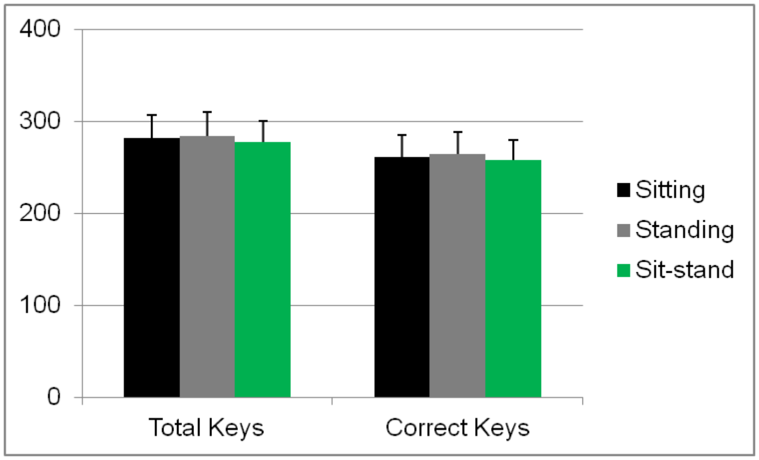


Figure 4-9 - Productivity during typing task, as measured by total key strokes per minute and correct key strokes per minute

Table 4-11: Typing

Total Keystrokes

Gender	Sit (per min)	Stand (per min)	Sit-Stand (per min)
Male	277.84 ± 55.13	284.50 ± 61.05	283.19 ± 60.55
Female	286.32 ± 65.34	284.47 ± 60.85	267.50 ± 52.67

ANOVA

	p
Gender x Workstation	0.7932
Gender	0.8697
Workstation	0.8707

Correct Keystrokes

Gender	Sit (per min)	Stand (per min)	Sit-Stand (per min)
Male	256.54 ± 54.73	263.85 ± 61.10	267.67 ± 67.78
Female	266.22 ± 70.87	265.35 ± 64.28	218.20 ± 47.01

ANOVA

	p
Gender x Workstation	0.2354
Gender	0.4044
Workstation	0.4591

Specific to the mousing task, females attempted significantly more mousing problems ($p = 0.025$; **Table 4-12**). However, no significant effect of gender was found when comparing the number of correct problems completed ($p = 0.134$).

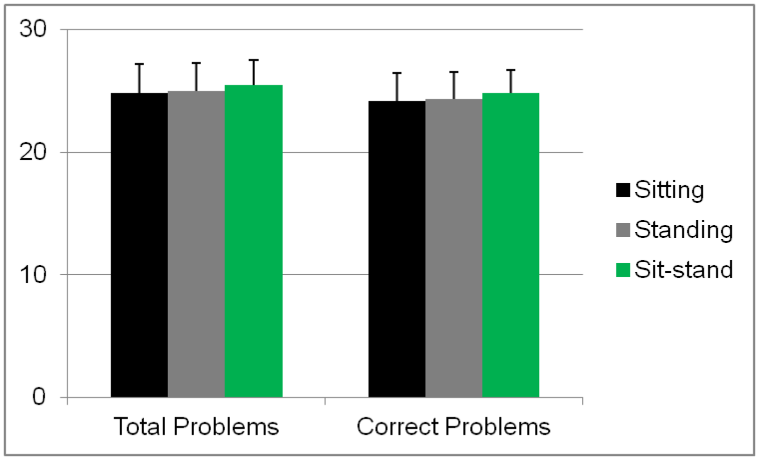


Figure 4-10 - Productivity during mousing tasks, as measured by total problems attempted per minute and correct problems completed per minute

Table 4-12: Mousing

Problems Attempted

Gender	Sit (per min)	Stand (per min)	Sit-Stand (per min)
Male	23.51 ± 3.91	23.30 ± 4.64	24.47 ± 4.71
Female	26.43 ± 5.22	26.98 ± 6.11	26.45 ± 5.68

ANOVA

	p
Gender x Workstation	0.8566
Gender	0.025
Workstation	0.9486

Correct Problems

Gender	Sit (per min)	Stand (per min)	Sit-Stand (per min)
Male	22.83 ± 4.13	22.68 ± 4.80	25.56 ± 5.39
Female	25.83 ± 5.13	26.35 ± 6.05	24.77 ± 5.82

ANOVA

	p
Gender x Workstation	0.321
Gender	0.134
Workstation	0.8586

4.5.5 Shifts, Drifts, and Fidgets

The total number of shifts per 20-minute block was found to be variable between participants, with the coefficient of variation (standard deviation / measured value*100%) ranging between approximately 50% to nearly 100%. No interactions were found between independent variables in the analyses of variance (**Table 4-13**). Additionally, no significant effects were found for any of the independent variables.

Table 4-13: Shifts

Males

Time (min)	Sit (per 20 min)	Stand (per 20 min)	Sit-Stand (per 20 min)
0-20	23.10 ± 21.08	27.60 ± 21.49	25.80 ± 14.34
20-40	32.80 ± 19.20	34.20 ± 22.33	35.60 ± 29.62
40-60	33.20 ± 20.86	31.50 ± 14.17	33.40 ± 19.07

Females

Time (min)	Sit (per 20 min)	Stand (per 20 min)	Sit-Stand (per 20 min)
0-20	20.00 ± 11.11	35.00 ± 33.00	34.00 ± 28.27
20-40	27.25 ± 15.81	44.75 ± 32.98	31.75 ± 20.87
40-60	29.25 ± 13.98	43.50 ± 27.54	32.88 ± 23.58

ANOVA

	p
Gender x Condition x Time	0.9599
Gender x Condition	0.2577
Gender x Time	0.9083
Condition x Time	0.976
Gender	0.5061
Condition	0.1482
Time	0.2149

With respect to instances of drifts per 20-minute block, no significant interactions were found in the analysis of variance (**Table 4-14**). The average number of instances of drift for each 20-minute block varied between a low of 28.63 to a high of 37.00.

Table 4-14: Drifts

Males

Time (min)	Sit (per 20 min)	Stand (per 20 min)	Sit-Stand (per 20 min)
0-20	28.90 ± 11.07	28.40 ± 17.74	35.70 ± 22.00
20-40	35.40 ± 14.69	35.60 ± 14.09	34.10 ± 12.61
40-60	37.00 ± 15.30	33.70 ± 14.69	37.00 ± 15.17

Females

Time (min)	Sit (per 20 min)	Stand (per 20 min)	Sit-Stand (per 20 min)
0-20	30.75 ± 10.22	28.63 ± 12.83	35.13 ± 16.36
20-40	31.75 ± 11.23	36.00 ± 13.80	32.50 ± 13.02
40-60	35.25 ± 11.41	36.63 ± 14.31	33.00 ± 12.00

ANOVA

	p
Gender x Condition x Time	0.9813
Gender x Condition	0.8359
Gender x Time	0.9281
Condition x Time	0.6754
Gender	0.7644
Condition	0.8457
Time	0.3098

Finally, the number of fidgets per 20-minute black was not significantly affected by any of the independent variables (**Table 4-15**). Nor were there any significant interactions in the 3-way analysis of variance.

Table 4-15: Fidgets

Males

Time (min)	Sit (per 20 min)	Stand (per 20 min)	Sit-Stand (per 20 min)
0-20	16.50 ± 11.21	21.40 ± 15.51	19.70 ± 11.97
20-40	20.00 ± 9.98	24.20 ± 14.39	23.70 ± 15.66
40-60	23.70 ± 17.76	22.80 ± 13.63	23.70 ± 14.67

Females

Time (min)	Sit (per 20 min)	Stand (per 20 min)	Sit-Stand (per 20 min)
0-20	16.38 ± 7.39	22.38 ± 14.29	19.88 ± 11.87
20-40	16.38 ± 5.76	25.00 ± 15.46	20.25 ± 12.46
40-60	18.50 ± 8.05	27.25 ± 13.99	19.13 ± 11.10

ANOVA

	p
Gender x Condition x Time	0.9602
Gender x Condition	0.5372
Gender x Time	0.8718
Condition x Time	0.9822
Gender	0.5696
Condition	0.1174
Time	0.4435

4.6 DISCUSSION

Working at a sit-stand workstation was able to reduce whole back discomfort when compared to either sitting or standing performed in isolation, and did not have a significant affect on worker productivity. However, from this study, it is not clear whether or not working at a sit-stand workstation type has a positive influence on seated or standing lumbar spine mechanics with respect to potential injury mechanisms.

Furthermore, when considering the results of this *in vivo* study it must be noted that the task chair used by the participants had both the armrests and backrest removed. Although there is anecdotal evidence suggesting that while performing computer tasks armrests and backrest are rarely utilized, there still remains the possibility that the lack of armrests and backrest could have affected the postures adopted by the participants as well as the discomfort scores reported.

4.6.1 Discomfort

Consistent with previous scientific literature, this study found that both prolonged sitting and prolonged standing work resulted in continually increasing levels of back discomfort (Roelen et al. 2008; Nelson-Wong et al. 2008; Gallagher et al. 2011). Working in a sit-stand paradigm, alternating between sitting and standing in a 15:5 minute ratio over an hour, showed the potential to reduce back discomfort. **Figure 4-7** showed that discomfort scores dramatically decrease in a manner coinciding with sit-stand posture changes. This was somewhat expected, as previous work has shown prolonged static postures result in increasing discomfort (Fenety and Walker 2002), and therefore changes in posture can likely reduce discomfort. Post-hock analysis revealed statistically significant lower average perceived whole back discomfort, in males, as early as 10 minutes into sit-stand, when compared to stand only (**APPENDIX B**). At 10 minutes, this difference may largely be attributed to the fact males generally experienced more discomfort while standing rather than sitting. Females on the other hand did not report statistically significant levels of lower discomfort until 20 minutes. This difference coincides with the first time participants were required to stand while working in the sit-stand paradigm. A curious interaction between gender and workstation type was found. When exploring the data further, a trend was found indicating males may generally developed higher levels of discomfort while standing whereas females developed higher levels of discomfort while sitting. This interaction may indicate a need for different recommended ratios between sitting and standing time for males versus females. The variability in reported perceived discomfort between participants remains a large limitation of any study using this as an outcome measure (Mader et al. 2003). Previous work by Nelson-Wong and Callaghan (2010a; 2010b) divided participants into groups based on whether or not the participant was classified as a pain developer. Isolating pain developers from non-pain developers likely reduces the variability in the reported discomfort scores and should be considered for any future sit-stand studies.

Previous work has shown the potential to associate shifts, drifts, and fidgets with pain development during prolonged standing (Lafond et al. 2009). Therefore, quantifying the number of shifts, drifts, and fidgets may be a more subjective manner to quantify the pain (or potentially discomfort) an individual may be experiencing during either prolonged standing or sitting work. Although the methods used in this study were not identical to previous methods used to quantify shifts, drifts, and fidgets; when compared to the measurements made in previous work

(Gallagher et al. 2013) the gross count of each variable showed relatively strong agreement. Unfortunately, no significant findings were found to associate a change in workstation type with any changes in the reported outcome measures. Nonetheless, it appears as though the sit-stand paradigm does have the potential to reduce discomfort but this potential may not truly be capitalized upon using a uniform 15:5 minute sit-stand ratio. Therefore, other ratios of sit-stand must still be explored in order to determine an optimal sit-stand ratio to maximize the potential benefits of this discomfort 'recovery' phenomenon. The optimal ratio may need to be gender specific, or perhaps even individual specific.

4.6.2 Potential Injury Mechanisms

Increases in lumbar flexion (Howarth et al. 2013), compressive loading (Parkinson and Callaghan 2009), and shear loading (Howarth and Callaghan 2013) have all been associated with potential spine injury mechanisms. A decrease in any or all of the aforementioned variables may have indicated a potential reduction in injury risk associated with working in a sit-stand paradigm. Although lumbar flexion during the sitting periods at the sit-stand workstation on average were lower than each of the analogous time periods during sit only work, it still remains unclear if this difference is clinically significant in the sense that it may be associated with a reduction in injury risk. While standing during sit-stand work, average lumbar extension (with respect to quiet standing as neutral) was higher than each analogous time period during stand only work; however, this difference was not statistically significant. Furthermore, no clear trends or statistically significant differences immerged when examining compressive and shear loading of the lumbar spine.

Focusing in on the discussion that reduced lumbar flexion during the sitting periods of sit-stand work may be a potential injury prevention mechanisms associated with sit-stand work, increased lumbar flexion resulting from prolonged seated work has previously been associated with a potential increase in injury risk (Howarth et al. 2013). Therefore, a decrease in lumbar spine flexion could indicate a lower level of 'exposure' even during the sitting portion of sit-stand work. Consequently, sit-stand work may be beneficial beyond just providing a postural break from sitting to reduce discomfort. Sit-stand work may also provide the potential to reduce injury risk by mitigating more extreme lumbar spine postures that develop in response to prolonged bouts of sedentary work. Curiously, the decrease in lumbar flexion during the sitting times of sit-stand, compared to the equivalent sitting times in sit only, did not coincide with a significant decrease in perceived discomfort (**APPENDIX B**), as might be expected based upon the work of O'Sullivan et al. (2006) showing pain response being positively associated with increased lumbar spine flexion.

In addition to posture being a factor in potential injury, increases in both compressive and shear loading of the spine have been shown to be positively associated with injury (Parkinson and Callaghan 2009; Howarth and Callaghan 2013). When comparing compressive loading during the sitting portion of the sit-stand condition to the sit only condition, no significant differences were found. In addition, no significant differences were found between the standing portion of the sit-stand condition and the equivalent time period during the stand only condition. These findings indicate working in a sit-stand paradigm does not likely have any additional benefits with respect injury prevention, from a compressive loading perspective, beyond that of simply limiting the total 'exposure' time to either prolonged sitting or standing respectively. In the A-P shear direction, although no significant differences were found between sitting and sit-stand or standing and sit-stand, there was a noteworthy trend found in sitting. Shear force in sitting was consistently higher in the sit only condition; however, this was still not significant ($p = 0.0963$). Considering a large portion of the A-P shear force in the spine during sitting likely results from the muscle force required to balance the L4/L5 joint moment caused by the forward tilt of the trunk, this trend is likely not a coincidence, but instead likely coincides with the significantly higher level of lumbar flexion during sitting in the sit only condition.

To further confound the discussion on the potential mechanical benefits of sit-stand on injury prevention, previous work has shown intervertebral joint injury risk is almost certainly not associated with only a single factor (ex. flexion angle, or compression, or shear), but likely a combination of factors (Howarth et al. 2013). Thus, although the study presented does provide a limited amount of biomechanical evidence that working in a sit-stand paradigm may provide some benefit in preventing injury, further work must still be completed to more fully explore this potential (Chapter 5).

Beyond a biomechanical perspective, there is an additional concern that working in a sit-stand paradigm may reduce worker productivity (Karakolis and Callaghan 2014). Based on the productivity measures reported in the present study, working in a sit-stand paradigm did not result in significantly lower levels of productivity. Previous work has shown a potential association between increasing discomfort and decreasing productivity in office workers during typing tasks (Haynes and Williams 2008; Liao and Drury 2000). This indicates an increase in productivity may have been expected during sit-stand work as a result of the decrease in discomfort. However, in both studies, the association was described as not strong, and it has also been conversely suggested that there may be a decrease in worker productivity associated with posture changes (Liao and Drury 2000), likely attributed to time loss in changing workstation configuration. A combination of the potentially opposing associations between increased productivity resulting from decreased worker discomfort in a sit-stand paradigm, and a decrease in productivity resulting from changing posture, may explain the zero net change in productivity between sit-stand and the other two conditions.

A question that arises from most laboratory study designs is: how can this be extrapolated to the 'real world.' In this particular study, the issue of an 8-hour workday as compared to 3 1-hour blocks becomes important. With particular respect to discomfort, it appears as though the level of 'recovery' during each standing phase becomes less adequate over time, and extrapolating to an 8-hour workday, sit-stand work in this 15:5 minute ration may not sufficient.

Finally, additional job stressors may also have an effect on job productivity, perceived discomfort, and perhaps even the posture adopted during routine office work. These job stressors can include productivity targets, performance reviews, and social pressures. None of these stressors were simulated in the lab. Fortunately, Robertson et al. (2013) have studied the impact of job stressors on sit-stand work and found that sit-stand workstations generally have a positive response in mitigating most job stressors.

4.7 CONCLUSIONS

This study has contributed foundational elements to guide usage recommendations and workstation configurations for the sit-stand paradigm by examining biomechanical and other differences between prolonged sitting, prolonged standing, and a sit-stand work paradigm. It was found that during the sitting periods while performing the tasks in a sit-stand paradigm, the subjects sat with less lumbar flexion compared to the postures they adopted while performing the tasks in a sit only paradigm. With respect to injury, this indicates there may be a potential protective mechanism associated with sit-stand work, as increased lumbar flexion has been associated with increased injury potential (Howarth et al. 2013). Further work is needed to quantify the beneficial potential of this mechanism.

Chapter 5 - Determining the Annulus Material Properties of the Porcine Intervertebral Disc

5.1 INTRODUCTION

This chapter is comprised of a two-part study. As this is the second experimental study presented in this thesis, the parts of this study will be referred to as: Study 2-A - Determining the elastic moduli for single and bi-layer specimens of annulus tissue; and Study 2-B - Determining the shear modulus for the annulus inter-lamellar matrix using a bi-layer sample.

Intervertebral disc herniation occurs when material from the nucleus pulposus breaches the surrounding composite laminate structure - the annulus fibrosus (Adams and Hutton 1985). Herniation has been identified as one potential mechanical pathway for low back pain (Boos et al. 1995; Maezawa and Muro 1992). The annulus serves as a semi-permeable pressure vessel containing the nucleus pulposus; therefore, for a herniation to occur the annulus must partially fail. A number of previous *in vitro* studies have shown a link between mechanical loading of the disc and disc herniation (Parkinson and Callaghan 2009; Drake et al. 2005; Callaghan and McGill 2001; Adams et al. 2000; Adams and Hutton 1983; Kuga and Kawabuchi 2001; Simunic et al. 2004; Yates and McGill 2004). Other studies have attempted to understand the material failure mechanisms associated with annulus failure and herniation progression (Veres et al. 2010; Veres et al. 2008; Tampier et al. 2007).

Intra- and inter-lamellar failures have been described as two distinct failure modes for the annulus (Tampier et al. 2007; Veres et al. 2008). Migration of the nucleus through annular layers has been shown to be a result of a combination of the two failure modes. Intra-lamellar failure is a breakdown of the tissue which makes up an individual layer of the annulus, whereas, inter-lamellar failure is the breakdown of the interface between two adjacent layers of annulus, the inter-lamellar matrix (Veres et al. 2008; Tampier et al. 2007).

The annulus is a composite laminate structure with adjacent lamellae connected by an inter-lamellar matrix. In addition to not being a homogeneous material it also exhibits regional structural and mechanical variations with respect to circumferential location and radial depth (Tsuji et al. 1993; Skaggs et al. 1994). Attempts to characterize the material properties of the annulus have involved uniaxial tensile testing of tissue samples (Holzapfel et al. 2005; Zhu et al. 2008). Biaxial loading of a single layer of the annulus has been performed to isolate single layer structural properties (Gregory and Callaghan 2008b), and a novel lap test has been developed to examine inter-lamellar matrix structural properties (Gregory et al. 2011). No studies have been done to characterize the material properties of a single or bi-layer of annulus under biaxial loading or the inter-lamellar matrix.

The most comprehensive study of annulus mechanics under biaxial load were completed by Gregory and Callaghan (2008b; 2011a; 2011b) and Gregory et al. (2011). However, due to logistical limitations in mechanical testing design, the studies were limited to reporting structural properties but not material properties. In the Gregory and Callaghan studies, the tungsten rakes used to hold the specimen and apply load during testing punctured the specimen, resulting in stress concentrations likely forming in the tissue proximal to the rake/tissue interface during tensile testing. A recent study has since confirmed the existence of stress concentrations using this technique (Karakolis and Callaghan 2014b). Therefore, in the present thesis study, total rake displacement was measured during testing to define an approximate loading rate for the mechanical testing. However, it was not a suitable measure of specimen elongation for subsequent strain calculations due to the local stress concentration caused by the tungsten rake punctures. Consequently, for the study described in this chapter, an alternative virtual point tracking method was used to define a gauge region (or region of interest) for the elongation measurements taken. The method is fully described in Section 5.4. This new method allowed for more precise strain measurements to be made, and subsequently, reporting of material properties rather than structural properties. In addition to the limitations presented concerning the rake/tissue interface, all previous biaxial mechanical testing has been conducted using equal (displacement controlled) loading in the orthogonal circumferential and longitudinal directions. Recent work suggests orthogonal surface strains may not be equal in these directions in the loaded annulus (Heuer et al. 2008). Therefore, when determining annulus material properties through biaxial tensile testing, it may be more appropriate to use unequal axis specific target displacements.

5.2 PURPOSE

The purpose of this two-part study was to determine the material properties for a single layer and bi-layer of annulus tissue, and the inter-lamellar matrix. Elastic and shear moduli were the two main dependent variables derived. Specifically, the first part of the study examined the effect of loading magnitude (target strain), unequal orthogonal direction loading versus equal orthogonal direction loading, and regional mechanical variations in the circumferential (anterior versus posterior) and radial (superficial or deep layers) directions of the intervertebral disc on elastic modulus for both a single and bi-layer layer of annulus. In addition, a descriptive comparison was made between the elastic modulus for a single layer versus a bi-layer of annulus. The descriptive comparison discussed the additive nature (or potentially lack there of) when comparing a single versus bi-layer sample of annulus. The second part of the study examined the effect of loading magnitude (target strain) and regional mechanical variations in the circumferential (anterior versus posterior) and radial (superficial or deep layers) directions of the intervertebral disc on the shear modulus of the inter-lamellar matrix.

5.3 HYPOTHESES

The three main hypotheses for Part A and two for Part B were as follows:

Part A

1) For both single layer and bi-layer samples, loading magnitude will not have a significant effect on elastic modulus.

   Rationale: Previous work has treated a single annulus layer as a linear elastic material (Holzapfel et al. 2005). Therefore, assuming a linear response, elastic modulus should not change with respect to loading magnitude unless damage is being induced. The protocol selected for this study has been selected to avoid any likelihood of inducing significant damage, since target strain will not exceed strains shown to be within the physiological range normally applied to the spine (Schmidt et al. 2009).

2) For both single layer and bi-layer samples, elastic modulus determined using equal orthogonal loads during biaxial loading will be significantly different from elastic modulus determined using unequal orthogonal loads.

   Rationale: The annulus is composed of tensile load bearing collagen fibers embedded within a ground substance. Assuming these fibers deform in response to the combination of the orthogonal loading components, this hypothesis assumes that changing the loading components from equal to unequal will cause a different response from the fibers and therefore change the elastic modulus.

3) For both single layer and bi-layer samples, the region of the annulus from which the tissue sample was obtained will impact elastic modulus.

   Rationale: The elastic modulus for annulus tissue samples taken from the anterior of the intervertebral disc will be greater than samples from the posterior of the disc since the lordotic shape of the spine likely results in larger tensile stresses in the anterior portion of the disc when the spine is in a neutral posture. The elastic modulus for annulus tissue samples taken from the superficial layers of the annulus will be greater than samples from the deep layers since the superficial layers likely are loaded with larger tensile stresses due to the geometrical arrangement relative to the joint center of rotation. This hypothesis and rationale agrees with previous work by Gregory and Callaghan (2011b) looking at a stress-stretch ratio in a two-layer annulus sample.

<u>Part B</u>

1) The shear modulus of the inter-lamellar matrix will be impacted by the radial location in the annulus and depth of the tissue sample.

   Rationale: Since the inter-lamellar matrix is loaded with similar principle stresses as the adjacent lamellae, regional variation in shear modulus should follow the same trends as the lamellar elastic modulus regional variation (see rationale for Study 2 – Hypothesis 1).

2) Loading magnitude will have a significant effect on the shear modulus.

   Rationale: Combined torsion and normal loading has been shown to accelerate the susceptibility for injury to the intervertebral disc (Drake et al. 2005). This hypothesis is based on the assumption that the annulus has a lower tolerance to shear loading when compared to normal loading. Therefore, shear loading to the same displacement magnitude as the normal straining study (Part A), will result in damage to the inter-lamellar matrix and a change in the measured shear modulus.

5.4 METHODS

This section will present the methods for both Study 2-A and Study 2-B. Common methods are presented together, followed by unique methods used for each separate part of the study.

5.4.1 Functional Spinal Units

Forty-five cervical (C3/C4 and C5/C6) porcine functional spinal units (FSU) were examined in these studies (Study 2-A, n = 30; Study 2-B, n = 15). The two disc levels used have previously been shown to be geometrically similar and therefore no mechanical differences were expected between levels (Tampier 2006). Specimens were stored frozen and thawed overnight prior to testing. Muscle and fat was removed leaving an osteoligamentous FSU. Posterior elements were removed to allow for access to the posterior aspects of the intervertebral discs. Each FSU was then sectioned using a stereoscopic zoom microscope (Nikon SMZ 1000, Nikon Instruments Inc., Melville, NY) and a peel technique (Gregory and Callaghan 2010) to yield four separate annulus tissue samples for mechanical testing.

5.4.2 Mechanical Testing

Testing was performed using a biaxial material testing system (**Figure 5-1**) specifically designed for thin biological tissues (BioTester 5000, Waterloo Instruments Inc., Waterloo, ON). Two sets of five-prong tungsten rakes oriented in orthogonal directions secured the tissue during testing (**Figure 5-2**). The opposite end of each rake was either rigidly fixed or fixed to a linear actuator. Tests were recorded with an image resolution of 1280x690 pixels (Sony XCD-910, Sony

Electronics Inc, Tokyo, Japan) and captured at a rate of 5 Hz. Temperature (30°C) and relative humidity (90%) were controlled throughout the pre-conditioning and testing protocol (Gruevski et al. 2014). Small reflective particles were placed on the surface of each sample to aid in surface tracking (Karakolis and Callaghan 2014b). The particles remained fixed to the hydrated surface of the sample as a result of the forces of adhesion.

Figure 5-1 - The BioTester 5000 was used to perform biaxial testing of both single and bi-layer samples of porcine annulus tissue.

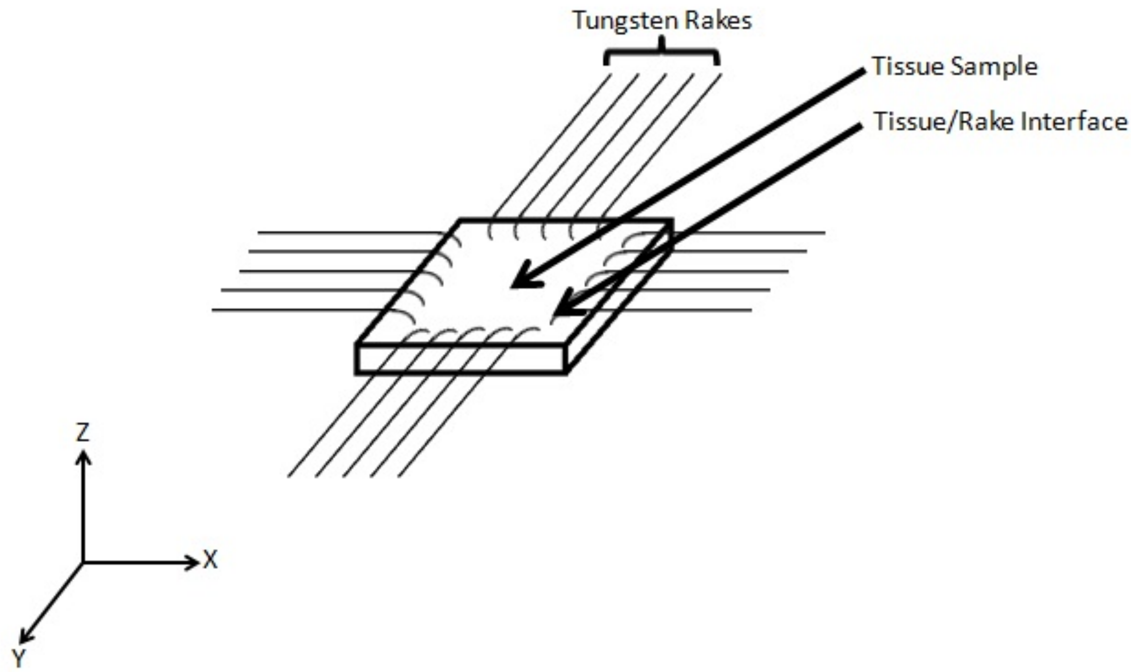


Figure 5-2 – Schematic of the biaxial tensile testing setup. Four sets of tungsten rakes held the tissue in place and were used to apply tensile force in two orthogonal directions simultaneously. For each pair of rake sets with a parallel orientation, one rake set was rigidly fixed in series with a load cell, the other was driven by a linear actuator.

5.4.3 Study 2-A Specific Methods

5.4.3.1 Loading

One hundred twenty tissue samples consisting of either a single annular layer or two adjacent annular layers (single layer n = 60; bi-layer n = 60) were obtained from four different locations within the annulus at either the C3/C4 of C5/C6 level of the porcine spine (**Figure 5-3**). The locations were: anterior – superficial, anterior – deep, posterior – superficial, and posterior – deep. This allowed for a maximum of 4 samples, either single layer or bi-layer, to be taken from each FSU specimen. A total of 30 FSUs were used for this part of the study. The superficial specimens were taken from one of the first 4 layers of the annulus. The deep specimens were taken from a layer between 5 and 10 layers deep in the annulus (Gregory and Callaghan 2011a). Each sample was prepared to be an approximately 4 mm x 4 mm square, using a stereoscopic zoom microscope (Nikon SMZ 1000, Nikon Instruments Inc., Melville, NY) to ensure that the sample obtained contained the desired number of layers. The thickness of each specimen was measured using a laser displacement measurement sensor (ZX-LD40L Smart Sensor, Omron Canada Inc., Toronto, ON).

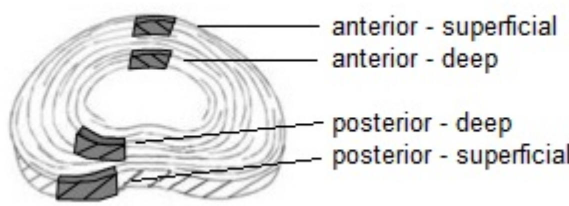


Figure 5-3 – Schematic representing the intervertebral disc showing the locations from which the tissue samples were taken. (Adapted from Gregory and Callaghan 2011a).

Tissue samples for were mounted in such that the orthogonal loading directions corresponded to the orthopaedic loading axes of the spine. Extreme care was taken to ensure the orientation of the specimen was such that one of the orthogonal directions (x-axis; or circumferential) represented disc hoop stress, and the other (y-axis; or axial) represented longitudinal stress.

Preconditioning: Samples were preconditioned at a strain rate of 1%/sec through five successive biaxial tensile stretch/recoveries to 10% peak strain in each orthogonal direction. Testing: Subsequent biaxial tensile stretch/recovery tests were performed at a constant strain rate of

2%/sec in bouts of 6 cycles. Peak strain for the first 3 cycles of each bout was unequal between loading axes, followed by 3 cycles of equal peak strain. For example, peak strain was 5% in the circumferential direction and 3% in the longitudinal direction for the first 3 cycles (unequal condition), then 5% in both directions for the next 3 cycles (equal condition). Peak strain was then increased by 5% for each successive bout, with the unequal condition always having a strain of 3/5 the peak strain in the longitudinal direction. (**Table 5-1**). The 3/5 ratio for the unequal loading condition was chosen to represent surface annulus strain reported during functional spinal unit loading (Heuer et al. 2008).

Table 5-1: Loading sequence used for both single and bi-layer biaxial mechanical testing.

Bout	Peak Circumferential Strain (%)	Peak Longitudinal Strain (%)	Number of Cycles
1a	5	3	3
1b	5	5	3
2a	10	6	3
2b	10	10	3
3a	15	9	3
3b	15	15	3
4a	20	12	3
4b	20	20	3
5a	25	15	3
5b	25	25	3
6a	30	18	3
6b	30	30	3

Two 2.5 N load cells with stated accuracy of 0.2% of rated full scale, and two stepper motor driven linear actuators with a resolution equivalent to 1 μm linear displacement (both sampled at 30 Hz) were used to track force and displacement throughout all mechanical testing. Force data were filtered with a dual pass second order Butterworth filter with a low pass cutoff frequency of 5 Hz.

5.4.3.2 Image Analysis

Images captured during mechanical testing were processed using the software package LabJoy 5.80 (Waterloo Instruments Inc., ON, Canada). Source images were defined as the first image of the third cycle in each bout. Virtual tracking points were then overlaid on the source image. Movements of all virtual points were tracked on successive images captured during each tensile test using a template-matching algorithm (Horst and Veldhuis 2008) that has been validated previously (Eilaghi et al. 2009; Karakolis and Callaghan 2012b). This algorithm relies on naturally occurring changes in surface texture of the tissue to track points on the sample. The reflective particles adhered to the surface of the sample provided additional surface features to ensure maximum fidelity of the surface tracking technique

Virtual points were arranged in four straight lines distributed parallel to the sets of tungsten rakes at a distance of approximately 0.5 mm from the rake tips. This formed a gauge region for each sample tested (**Figure 5-4**). Average displacement for all the virtual points in a given line was calculated for the direction perpendicular to that line. For example, in **Figure 5-4** the displacement of the six points in the vertical line on the left was averaged in the horizontal direction. The difference in average displacement between the two parallel lines served as a measure of specimen elongation (i.e. the difference in average horizontal displacement between the two vertical lines in **Figure 5-4**).

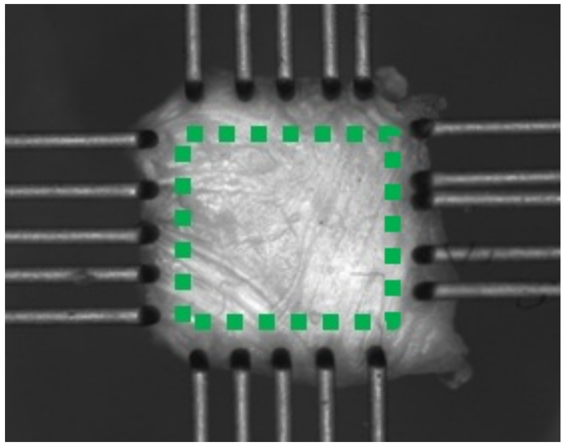


Figure 5-4 – Image of an annulus tissue sample being held in place in the material testing system. The green squares represent the virtual tracking points. The points form the gauge region in both orthogonal directions that were used to define initial length for the strain calculations**.**

5.4.3.3 Stress, Strain, and Modulus determination

Engineering strain, for each orthogonal direction, was calculated as elongation divided by initial specimen length. Normal stress was calculated as an engineering stress; and was therefore, force divided by the cross-sectional area of the sample in the plane normal to the force.

Stress-strain curves were created for both directions, for each specimen. Instantaneous elastic moduli were determined as the slope for each region of the stress-strain curve that met the linearity criteria. The linearity criterion was defined by a less than 2% change in instantaneous slope for 3 successive data points on the stress-strain curve (Beer and Johnston 2004). Instantaneous slope was calculated for each data point using a nearest neighbour method. In the event the tensile testing caused the sample to yield, a yield point was defined as any preceding the point where instantaneous elastic modulus decreased (Beer and Johnston 2004).

5.4.4 Study 2-B Specific Methods

5.4.4.1 Loading

Sixty bi-layer tissue samples (approx. 7 mm x 4 mm x 0.36 mm), consisting of two adjacent layers of annulus and the connecting inter-lamellar matrix, were obtained from the same four locations as Study 2-A (**Figure 5-3**). A total of 15 additional FSUs were used for this part of the study. For all tissue samples in Study 2-B, collagen fibres within the tissue sample were aligned to represent the orthopaedic loading axes present in the spine. Orientation was such that one of the orthogonal directions represented disc hoop stress (x-axis; or circumferential), and the other represented longitudinal stress (y-axis; or axial).

Samples were prepared for shear loading using a novel lap test method previously described (Gregory et al. 2011). Specimens were 3 mm longer in the circumferential direction (7mm in length) than longitudinal direction (4mm in width) in order to accommodate an additional dissection to prepare them for single axis shear loading. The bi-layer sample were dissected such that approximately 1-2 mm of tissue was removed from one layer on one end, and another 1-2 mm of tissue was removed from the opposite layer on the opposite end. Two parallel rake sets were used to apply the shear load. One rake set punctured the single layer on one end, and the other rake set punctured the opposite layer on the opposite end (**Figure 5-5**). In this configuration, displacing the rakes caused shear loading of the inter-lamellar matrix. Since rake displacement could not be used as a simple surrogate to calculate peak shear strain during mechanical testing in the same manner as normal strain in Study 2-A, loading was carried out in bouts nearly identical to that described in Study 2-A (**Table 5-1**). However, since loading was only in a single axis, there was no condition assessing differences between equal and unequal loading conditions.

5.4.4.2 Image Analysis

Image analysis and point tracking was performed using the same techniques described in Section 5.4.3.2. However, instead of creating a square gauge region with the virtual points, four parallel lines of virtual tracking points were created and tracked (**Figure 5-5**).

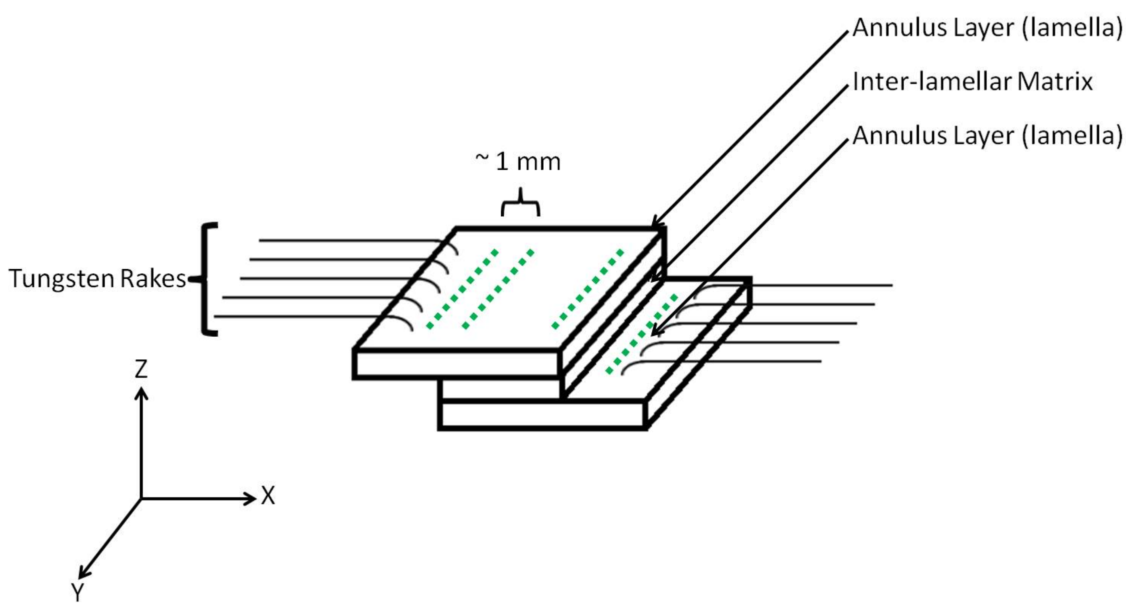


Figure 5-5 – Mechanical testing configuration for shear loading. The green dots represent the virtual points used to calculate shear strain.

5.4.4.3 Stress, Strain, and Modulus determination

Applied shear stress (**τ**) was calculated as the load measured by the load cell in series with the rake sets divided by the initial area of the tissue sample in the XZ plane. The method used to determine the average shear strain (**γ**) and shear modulus (**G**) is illustrated in **Figure 5-6**.

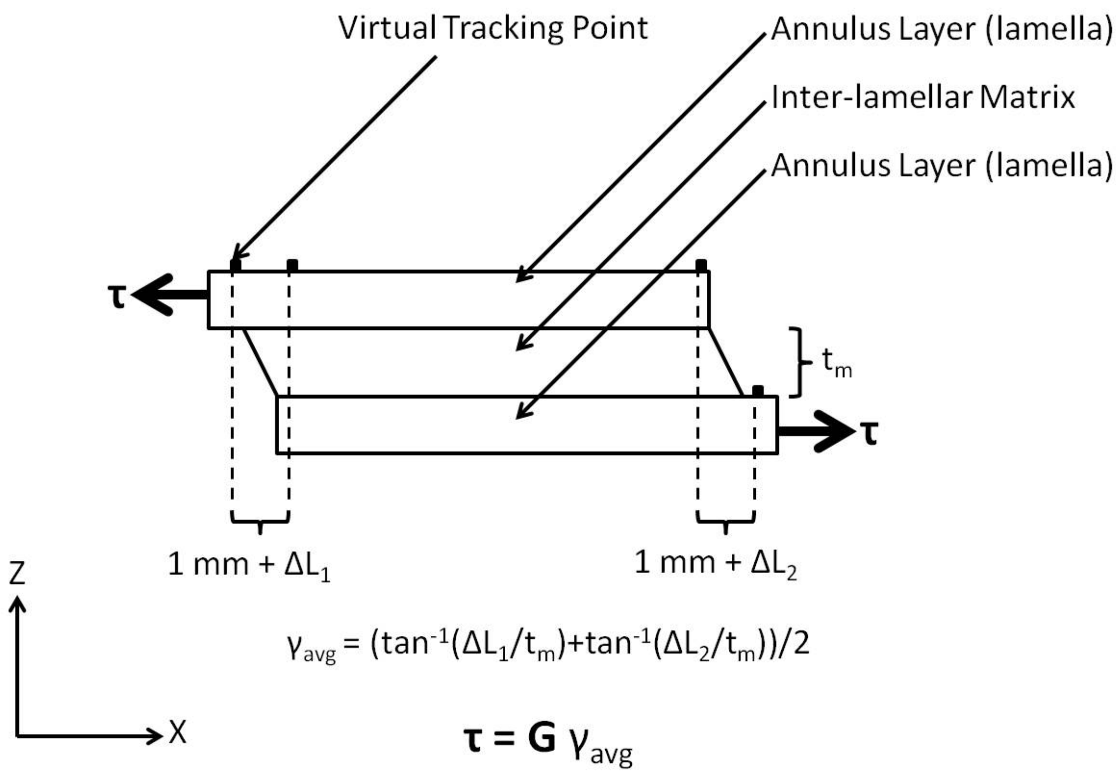


Figure 5-6 – Schematic depicting shear modulus determination. ΔL – Change in distance between parallel lines of virtual tracking points resulting from shear load. The subscripts 1 and 2 indicate the change in distance measured on both sides of the sample. tm – thickness of the inter-lamellar matrix. γavg – Shear strain was calculated for both ends of the tissue sample and averaged to determine an average shear strain. G – calculated Shear modulus.

5.4.5 Statistical Analysis

For the purposes of statistical analysis, the elastic modulus dependent measure was analyzed using the same technique for both the single layer and bi-layer samples. Elastic modulus in each orthogonal direction was treated independently. Elastic modulus was compared using a three-way mixed model analysis of variance with location as a between factor and peak normal strain and unequal/equal as a within or repeated factors. Statistical significance was accepted at the p=0.05 level and post-hoc pairwise testing was completed as required. A two-way mixed model was used for the shear modulus, with location and peak shear strain as between and within factors respectively. Significance was accepted at the p=0.05 level and post-hoc pairwise testing was completed as required.

5.5 RESULTS

The average thickness for a single layer of annulus tissue was found to be 0.13 ± 0.03 (SD) mm and the average thickness for a bi-layer was found to be 0.36 ± 0.07 mm. The difference between the thickness of two single layer samples (ex. 0.13 mm * 2 = 0.26 mm) and a bi-layer sample was considered to be the thickness of the inter-lamellar matrix. Therefore, the average thickness of the inter-lamellar matrix was 0.10 mm.

The elastic modulus calculated in the circumferential direction for a single layer of annulus loaded under uneven biaxial peak strain varied between 0.36 and 1.44 MPa depending on peak load and sample location (**Table 5-2**). For loading under even biaxial peak strain, the calculated elastic modulus varied between 0.42 and 1.55 MPa. For the circumferential direction, peak strain ($p < 0.001$) and sample location ($p = 0.042$) were both found to have a significant effect on elastic modulus. Loading under uneven or even biaxial strain was found to not have a significant effect on the elastic modulus ($p = 0.847$). Post-hoc pairwise comparisons can be found in **APPENDIX C**. There were no consistent trends with respect to changes in elastic modulus.

The elastic modulus calculated in the longitudinal direction for a single layer of annulus loaded under uneven biaxial peak strain varied between 0.28 and 0.85 MPa depending on peak load and sample location (**Table 5-3**). For loading under even biaxial peak strain, the calculated elastic modulus varied between 0.32 and 1.15 MPa. Similar to the circumferential direction, for the longitudinal direction, peak strain and sample location were both found to have a significant effect on elastic modulus ($p < 0.001$ for both). Contrary to the circumferential direction, loading under even or uneven biaxial strain was found to have a significant effect of the elastic modulus calculated for the longitudinal direction (p = 0.001). Post-hoc pairwise comparisons can be found in **APPENDIX C**. For the larger peak strains, even loading resulted in larger elastic moduli.

The loading and unloading curves during mechanical testing were found to be fairly typical for biological soft tissue. For typical raw data force displacement curves, please refer to **APPENDIX D**.

Table 5-2: Single Layer average elastic moduli (E) in the circumferential direction (x-direction) for each test condition. Bracketed values indicate standard deviation. Ant Sup - Anterior Superficial; Ant Deep - Anterior Deep; Post Sup - Posterior Superficial; Post Deep - Posterior Superficial. UE - Unequal strain condition; E - Equal strain condition. 5,10,15,20,25,30 represent the peak strain in the x-direction. N = 12 for each group. All values are in MPa.

		5	10	15	20	25	30	p
Ant Sup	UE	0.89 (0.79)	0.71 (0.48)	0.81 (0.62)	0.87 (0.94)	1.17 (1.04)	0.95 (0.69)	0.042
	E	0.63 (0.61)	0.50 (0.32)	0.81 (0.56)	0.98 0.89	0.95 (0.70)	0.92 (0.61)	
Ant Deep	UE	0.66 (0.24)	1.47 (1.14)	0.96 (0.75)	1.31 (1.05)	1.23 (0.78)	1.18 (0.67)	
	E	0.80 (0.88)	1.12 (0.82)	0.96 (0.87)	1.24 (1.06)	1.17 (0.88)	1.32 (0.59)	
Post Sup	UE	0.36 (0.24)	0.76 (0.61	0.66 (0.46)	0.72 (0.58)	1.25 (0.94)	1.01 (0.71)	
	E	0.60 (0.48)	0.56 (0.43	0.90 (0.84)	0.93 (0.95)	1.10 (0.62)	1.55 (0.95)	
Post Deep	UE	0.59 (0.38)	0.58 (0.38)	0.82 (0.75)	1.17 (1.11)	1.43 (1.14)	1.41 (1.06)	
	E	0.42 (0.22)	0.68 (0.52)	1.19 (1.00)	0.92 (0.64)	1.09 (0.72)	1.34 (0.80)	
p	<0.001							

*p=0.847 for Unequal or Equal strain variable

Table 5-3: Single layer average elastic moduli (E) in the longitudinal direction (y-direction) for each test condition. Bracketed values indicate standard deviation. Ant Sup - Anterior Superficial; Ant Deep - Anterior Deep; Post Sup - Posterior Superficial; Post Deep - Posterior Superficial. UE - Unequal strain condition; E - Equal strain condition. 5,10,15,20,25,30 still represent the peak strain in the x-direction. N = 12 for each group. All values are in MPa.

		5	10	15	20	25	30	p
Ant Sup	UE	0.47 (0.34)	0.51 (0.37)	0.57 (0.61)	0.28 (0.19)	0.50 (0.85)	0.51 (0.48)	<0.001
	E	0.35 (0.20)	0.49 (0.32)	0.44 (0.24)	0.56 (0.70)	0.72 (0.73)	0.36 (0.19)	
Ant Deep	UE	0.47 (0.33)	0.31 (0.19)	0.42 (0.45)	0.35 (0.17)	0.91 (1.26)	0.63 (0.71)	
	E	0.34 (0.23)	0.57 (0.46)	0.92 (1.10)	0.60 (0.55)	0.89 (0.77)	0.83 (0.73)	
Post Sup	UE	0.46 (0.34)	0.28 (0.20)	0.62 (0.67)	0.40 (0.41)	0.51 (0.87)	0.46 (0.46)	
	E	0.32 (0.17)	0.42 (0.34)	0.42 (0.21)	0.93 (0.82)	1.15 (1.13)	0.81 (0.60)	
Post Deep	UE	0.67 (0.44)	0.67 (0.60)	0.84 (0.88)	0.58 (0.60)	0.85 (0.96)	0.85 (0.85)	
	E	0.51 (0.57)	0.77 (0.49)	0.42 (0.21)	0.93 (0.82)	1.15 (1.13)	0.81 (0.60)	
p	<0.001							

*p=0.001 for Unequal or Equal strain variable

The elastic modulus calculated in the circumferential direction for a bi-layer sample of annulus loaded under uneven biaxial peak strain varied between 0.26 and 1.41 MPa depending on peak load and sample location (**Table 5-4**). For loading under even biaxial peak strain, the calculated elastic modulus varied between 0.25 and 1.51 MPa. For the circumferential direction, peak strain was found to have a significant effect on elastic modulus ($p < 0.001$); however, sample location was not found to have a significant effect on elastic modulus ($p = 0.153$). Loading under uneven or even biaxial strain was found to not have a significant effect on the elastic modulus ($p = 0.345$). Post-hoc pairwise comparisons for specific group differences can be found in **APPENDIX C**.

The elastic modulus calculated in the longitudinal direction for a bi-layer sample of annulus loaded under uneven biaxial peak strain varied between 0.28 and 1.20 MPa depending on peak load and sample location (**Table 5-5**). For loading under even biaxial peak strain, the calculated elastic modulus varied between 0.29 and 1.16 MPa. For the longitudinal direction, peak strain ($p = 0.003$) and sample location ($p = 0.002$) were both found to have a significant effect on elastic modulus. Loading under even or uneven biaxial strain was not found to have a significant effect of the elastic modulus calculated for the longitudinal direction ($p = 0.183$). Post-hoc pairwise comparisons for specific group differences can be found in **APPENDIX C**.

Trends for changes in elastic modulus by sample location and target strains are illustrated in **Figure 5-7**. The figure also compares the elastic moduli calculated for both single and bi-layer samples of annulus tissue.

Table 5-4: Bi-layer average elastic moduli (E) in the circumferential direction (x-direction) for each test condition. Bracketed values indicate standard deviation. Ant Sup - Anterior Superficial; Ant Deep - Anterior Deep; Post Sup - Posterior Superficial; Post Deep - Posterior Superficial. UE - Unequal strain condition; E - Equal strain condition. 5,10,15,20,25,30 represent the peak strain in the x-direction. N = 12 for each group. All values are in MPa.

		5	10	15	20	25	30	p
Ant Sup	UE	0.26 (0.17)	0.55 (0.23)	0.86 (0.80)	0.88 (0.92)	1.41 (1.02)	0.98 (0.90)	
	E	0.25 (0.09)	0.63 (0.47)	0.46 (0.29)	0.55 (0.40)	0.80 (0.89)	0.83 (0.77)	
Ant Deep	UE	0.34 (0.18)	0.70 (0.55)	1.10 (0.71)	0.76 (0.44)	0.92 (0.77)	1.16 (0.79)	
	E	0.72 (0.48)	0.63 (0.56)	0.78 (0.49)	0.75 (0.51)	1.51 (1.09)	1.16 (1.15)	
								0.153
Post Sup	UE	0.32 (0.20)	0.51 (0.45)	0.55 (0.57)	0.64 (0.61)	0.94 (1.23)	0.55 (0.40)	
	E	0.73 (0.48)	0.87 (0.61)	0.60 (0.62)	0.57 (0.45)	0.58 (0.82)	0.61 (0.84)	
Post Deep	UE	0.40 (0.30)	0.52 (0.36)	0.57 (0.49)	0.59 (0.59)	0.93 (0.91)	0.89 (0.87)	
	E	0.51 (0.40)	0.34 (0.28)	0.59 (0.49)	0.86 (1.04)	0.64 (0.87)	0.94 (0.98)	
p	<0.001							

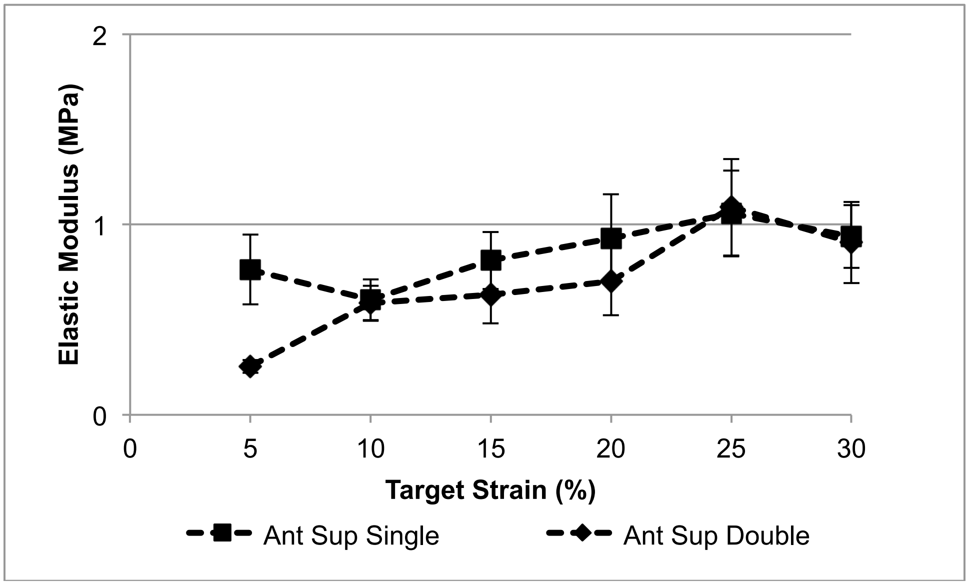
*p=0.345 for Unequal or Equal strain variable

Table 5-5: Bi-layer average elastic moduli (E) in the longitudinal direction (y-direction) for each test condition. Bracketed values indicate standard deviation. Ant Sup - Anterior Superficial; Ant Deep - Anterior Deep; Post Sup - Posterior Superficial; Post Deep - Posterior Superficial. UE - Unequal strain condition; E - Equal strain condition. 5,10,15,20,25,30 still represent the peak strain in the x-direction. N = 12 for each group. All values are in MPa.

		5	10	15	20	25	30	p
Ant Sup	UE	0.77 (1.08)	0.52 (0.36)	0.44 (0.33)	0.28 (0.19)	0.40 (0.16)	0.43 (0.27)	
	E	0.51 (0.40)	0.48 (0.69)	0.59 (0.49)	0.73 (0.79)	0.74 (0.90)	0.79 (0.81)	
Ant Deep	UE	0.35 (0.26)	0.43 (0.20)	0.60 (0.60)	0.92 (0.94)	1.08 (1.15)	1.00 (1.20)	
	E	0.56 (0.42)	0.52 (0.58)	0.50 (0.38)	0.39 (0.34)	1.16 (1.03)	0.83 (0.87)	
								0.002
Post Sup	UE	0.35 (0.26)	0.40 (0.20)	0.38 (0.34)	0.31 (0.24)	0.44 (0.54)	0.83 (1.08)	
	E	0.58 (0.41)	0.29 (0.15)	0.36 (0.21)	0.50 (0.40)	0.91 (0.95)	0.92 (0.87)	
Post Deep	UE	0.35 (0.26)	0.39 (0.21)	0.46 (0.38)	0.50 (0.58)	1.20 (1.04)	1.16 (1.00)	
	E	0.56 (0.42)	0.34 (0.16)	0.47 (0.62)	0.87 (0.60)	0.88 (0.63)	1.03 (0.97)	
p	0.003							

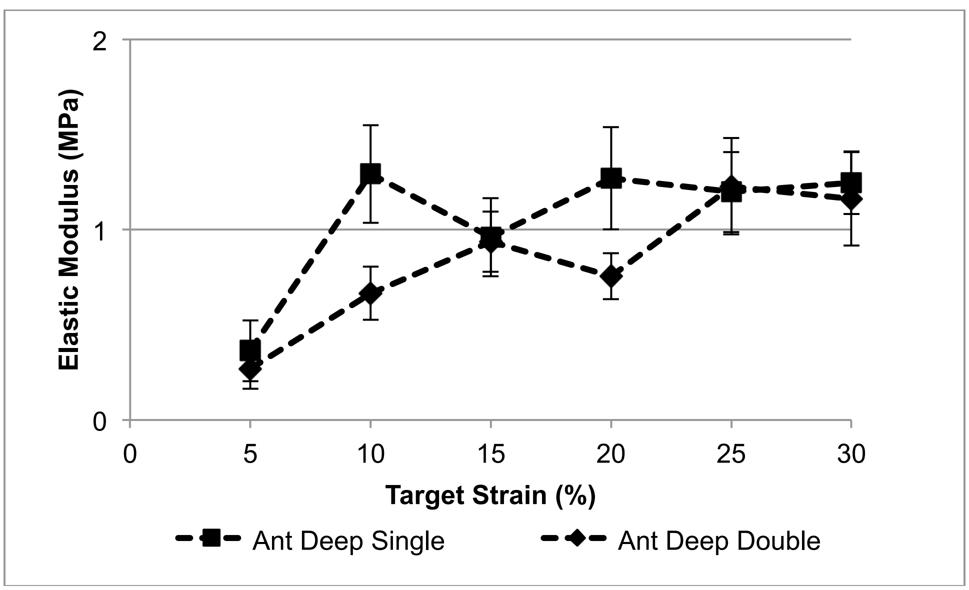
*p=0.183 for Unequal or Equal strain variable

A)



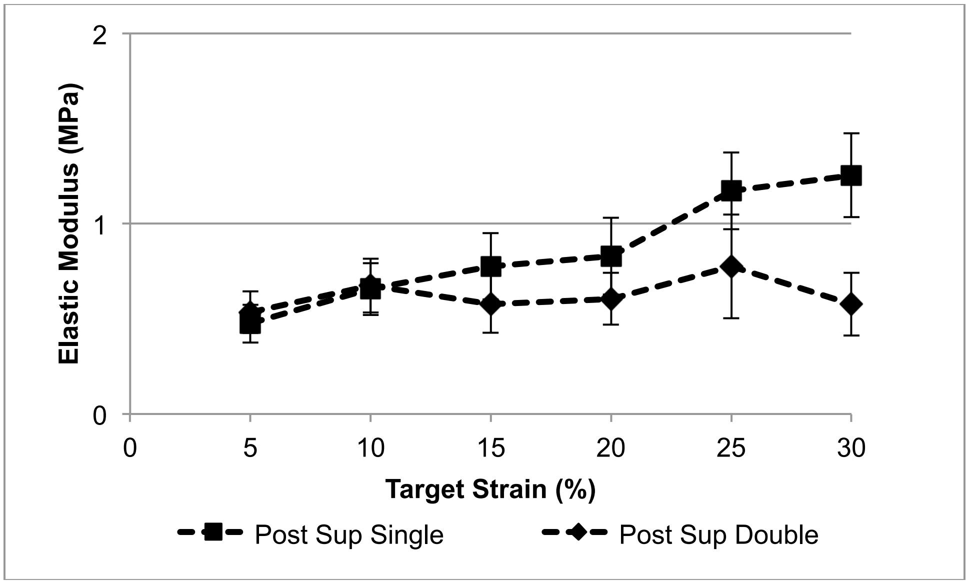
2
1
0
Elastic Modulus (MPa)
0
5
10
15
20
25
30
Target Strain (%)
Ant Sup Single
Ant Sup Double

B)



2
1
0
Elastic Modulus (MPa)
0
5
10
15
20
25
30
Target Strain (%)
Ant Deep Single
Ant Deep Double

C)



D)

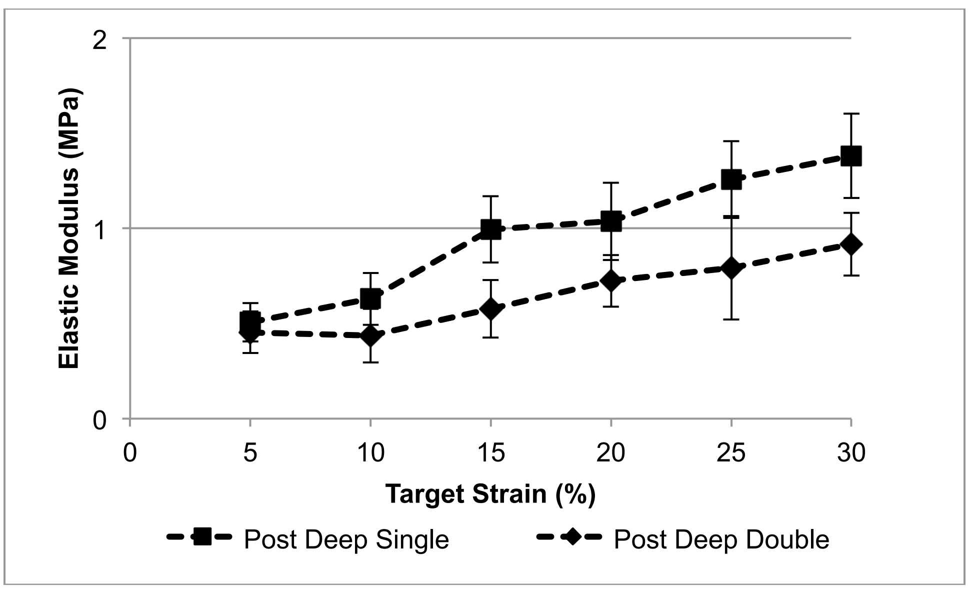


Figure 5-7: Comparison between the elastic modulus (E) of a single layer and bi-layer annulus sample in the circumferential direction (x-direction), with respect to target strain. Results are collapsed across equal and unequal loading conditions. Error bars represent standard error. A) Anterior Superficial; B) Anterior Deep; C) Posterior Superficial; D) Posterior Deep.

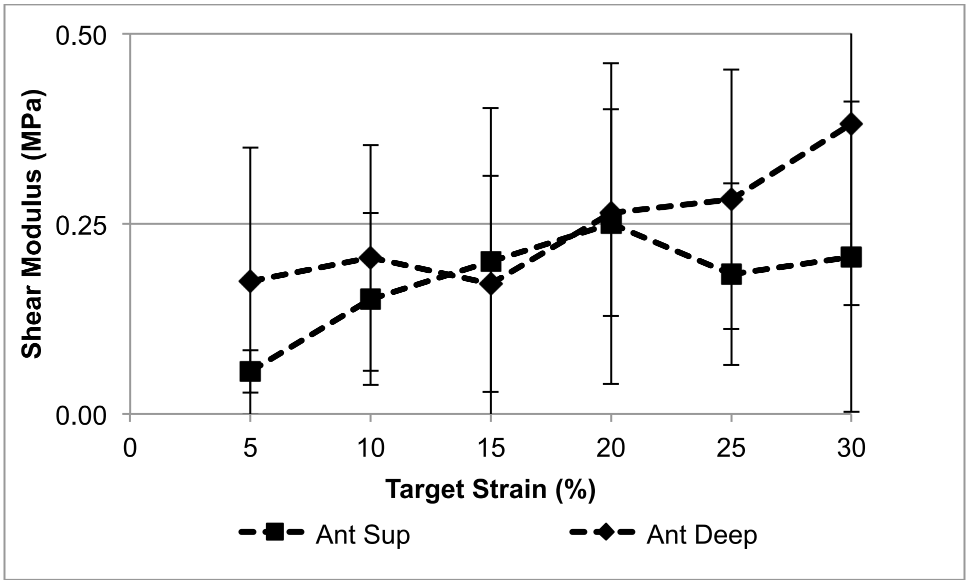
Average shear modulus in the longitudinal direction for a bi-layer sample of annulus loaded uniaxial in a lap test configuration varied between 0.05 and 0.38 MPa, depending on peak load and sample location (**Table 5-6**). Peak strain ($p = 0.012$) and sample location ($p < 0.001$) were both found to have a significant effect on shear modulus. Post-hoc pairwise comparisons for specific group differences can be found in **APPENDIX C**.

The trends for changes in shear modulus by sample location and target strains are illustrated in **Figure 5-8**.

Table 5-6: Average shear moduli (G) for a bi-layer sample of annulus in the circumferential direction (x-direction) for each test condition. Bracketed values indicate standard deviation. Ant Sup - Anterior Superficial; Ant Deep - Anterior Deep; Post Sup - Posterior Superficial; Post Deep - Posterior Superficial. 5,10,15,20,25,30 represent the peak strain in the x-direction. N = 12 for each group. All values are in MPa.

	5	10	15	20	25	30	p
Ant Sup	0.06 (0.03)	0.15 (0.11)	0.20 (0.20)	0.25 (0.21)	0.18 (0.12)	0.21 (0.20)	
Ant Deep	0.17 (0.18)	0.21 (0.15)	0.17 (0.14)	0.27 (0.14)	0.28 (0.17)	0.38 (0.24)	
							<0.001
Post Sup	0.05 (0.02)	0.10 (0.10)	0.15 (0.12)	0.17 (0.13)	0.21 (0.15)	0.13 (0.10)	
Post Deep	0.20 (0.20)	0.28 (0.16)	0.20 (0.16)	0.19 (0.14)	0.24 (0.14)	0.19 (0.19)	
p	0.012						

A)



B)

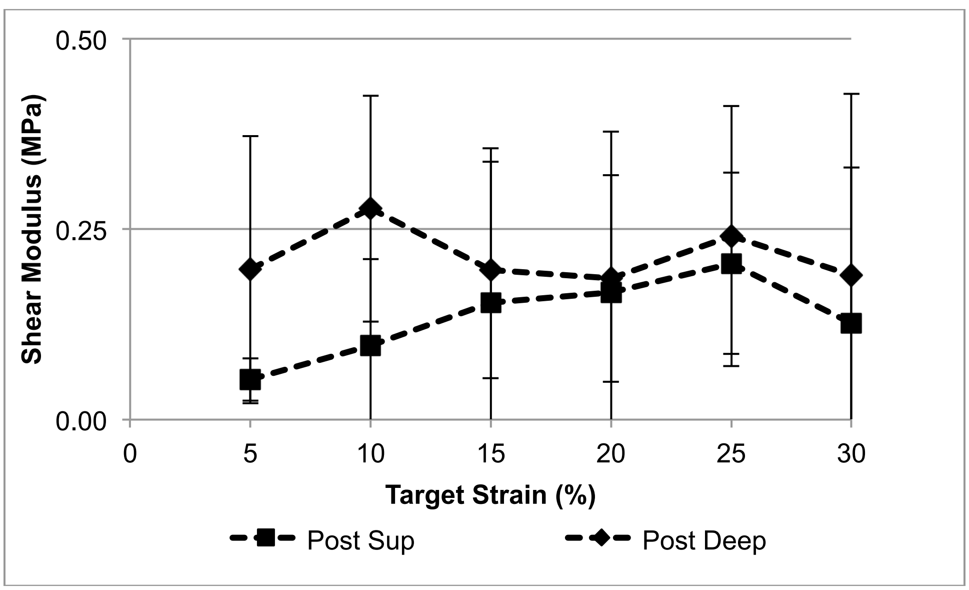


Figure 5-8: Comparison between the shear modulus (G) based on location (superficial versus deep) in the circumferential direction (x-direction), with respect to target strain. Error bars represent standard error. A) Anterior - Superficial versus Deep; B) Posterior - Superficial versus Deep.

5.6 DISCUSSION

Revisiting the hypotheses for this study, it appears as though the material properties of annulus lamellae and inter-lamellar matrix both vary by location. However, load magnitude also appears to have a significant effect on elastic modulus indicating that annulus tissue may not be as linear elastic as expected in the loading range tested. Lastly, when unequal load was applied in two orthogonal directions, the material properties in the longitudinal direction appear to be significantly affected; whereas, in the circumferential direction material properties are not significantly affected.

Although post-hoc testing revealed somewhat inconsistent findings at times, generally, the deeper layers of annulus tissue were stiffer (higher elastic modulus) than the more superficial layers. Functionally, this may be beneficial since due to the geometry of the annulus, during both spine flexion and extension, deeper layers of the annulus likely do not deform to the same extent as outer layers. With respect to circumferential location (anterior versus posterior), no clear trends emerged. It may be expected that lower stiffness is functionally advantageous in the posterior region since a larger range of spine flexion may cause increased deformation in the posterior region compared to deformation in the anterior caused by spine extension. Nonetheless, regional difference in stiffness was not consistently observed in this direction.

In the context of previous work exploring the elastic modulus of a single layer of annulus tissue, the 0.35 – 1.55 MPa reported in this study share some overlap with the values reported by Holzapfel et al. (2005). Holzapfel et al. (2005) reported three elastic moduli ranges for a single layer under uniaxial loading: E_{low}(0-0.1 MPa), E_{medium} (0.1-0.5 MPa), and E_{high} (0.5-1 MPa). The high end 1.55 MPa reported in the present study is considerably higher than the 1 MPa maximum value reported by Holzapfel et al. (2005). This discrepancy may be related to the difference in testing methods. Holzapfel et al. (2005) tested the specimens under uniaxial loading, whereas the present study tested all normally loaded (ie. not shear loaded) specimens under biaxial loading conditions. Biaxial loading is a closer approximation to the loading environment experienced by annulus tissue in a physiological setting. Holzapfel et al. (2005) continued their analysis beyond the gross elastic modulus for a single layer of annulus and derived values for the elastic moduli of single layers of collagen fibers. Due to the logistical limitations concerning the primary fiber orientation during testing in the present study (expanded upon in Section 5.6.1), a further analysis to the extent presented by Holzapfel et al. (2005) was not possible.

5.6.1 Logistical Limitations

During sample preparation (described in Section 5.4.3), the orientations of the collagen fibers in the intact disc can be easily altered. Although unintentional, the very process of dissecting out a sample of annulus tissue using a scalpel and clamps can cause a re-orientation of the fibers. In addition to the change in fiber orientation, the number of cross-link fibers between lamellae (for a bi-layer sample) that get severed during the dissection may also vary as their location and distribution is unknown and variable both within and between FSUs (Veres et al. 2008). This variability is dependent on the initial number of cross-links in the area from which the sample was obtained. These two logistical limitations prevent a further analysis to determine collagen fiber elastic moduli and may be one of the factors contributing to some of the variability in the reported data both within Part A of the study and between Part A and Part B of the study. Fortunately, the boundary conditions during the testing protocol allow the fibers to re-arrange and resist the loading in a manner that is likely similar to that in a physiological situation. This re-arrangement would occur during the pre-load and pre-conditioning phases of the protocol prior to test condition initiation (also described in Section 5.4.3).

Thickness measures reported in this study agree well with previous work measuring the thickness of single (Gregory and Callaghan 2011a) and bi-layer (Gregory and Callaghan 2011b) samples of porcine annulus tissue prepared using similar methods. However, measures for the thickness of a single layer of human annulus have been previously reported 2-3 times higher, approximately 0.38 mm (Holzapfel et al. 2005). This evidence suggests a single layer of human annulus may be considerably thicker than the porcine equivalent. When comparing their average thickness to previous work, Holzapfel et al. (2005) suggest a reason their thickness is larger than the 0.22 mm average thickness that Marchand and Ahmed (1990) reported for human annulus is the Holzapfel et al. (2005) technique is, 'biased (too [sic] large values) in the sense that thicker lamellae were preferably used for specimen preparations.' (p. 138). Alternatively, it is unclear how Holzapfel et al. (2005) verified the specimens tested were only a single annular layer. For the study presented in this thesis document, even though a considerable effort was made to verify the number of annulus layers (single or bi-layer) using a stereoscopic zoom microscope, due to the relatively unorganized nature of the porcine annulus structure the limitation still exists that some samples may have contained more layers or partial layers than the number reported.

5.6.2 Effect of Independent Variables

Part A

For both single layer and bi-layer samples, peak strain had a significant effect on elastic modulus. Although previous work has treated single and bi-layer annulus tissue samples as a linear elastic material throughout a relatively large loading range (Holzapfel et al. 2005; Gregory and Callaghan 2011a; Gregory and Callaghan 2011b), the results presented here indicate the loading profile for annulus tissue likely contains a large 'toe region' before the linear elastic region. This toe region may extend as far as 10% strain, and this may explain the finding that peak strain had a significant effect on elastic modulus. In terms of the relevance of this finding, it is unclear what effect modeling the annulus as a non-linear elastic material to a strain of 10% may have on future work. Modeling annulus material in a context of injury potential is further discussed in the following chapter, and a comparison of a linear versus non-linear material model is made there. Consistent with the original hypothesis, target strains did not exceed strains shown to be within the physiological range normally applied to the spine (Schmidt et al. 2009).

For both single layer and bi-layer samples in the circumferential direction, the elastic modulus determined using equal orthogonal loads during biaxial loading was not significantly different from the elastic modulus determined using unequal orthogonal loads. Originally, it was hypothesized that unequal loading would affect the elastic modulus. This discrepancy may either be a result of the uneven loading differential being too small to cause a significant effect, or could be related to the fiber re-orientation process during pre-loading and pre-conditioning. If the later is true, uneven versus even loading may be more of an issue at higher loading levels or in mechanical testing where the specimen is more constrained. Perhaps once the fibers re-orientated to resist loading in the primary loading direction, loading in the orthogonal direction may have had a lower magnitude effect on the modulus of the tissue sample.

Fiber orientation/re-orientation may have also had an effect beyond those tested for through the *a priori* hypotheses. Although not tested through inferential statistical testing, the elastic modulus for bi-layer samples was not consistently higher than the single layer modulus across conditions. It may have been expected that the inter-lamellar matrix in the bi-layer samples would have provided some re-enforcement and the collagen cross-bridges between layers would have also contributed to making the bi-layer samples stiffer. Not only was this not found, across a number of testing conditions, the bi-layer samples were surprisingly less stiff than the single layer samples. One possible theory for this finding could be, instead of stiffening the bi-layer samples through re-enforcement, the collagen cross-bridges between layers further constrained the fibers within each layer. The constrained collagen fibers may not have been able to re-orient themselves to as great an extent and therefore been less able to bear load.

Part B

The shear modulus of the inter-lamellar matrix was significantly affected by the radial location in the annulus and depth of the tissue sample. This was also consistent with the original hypothesis. Trends similar to those found in the normal loading scenarios (Part A) were found in shear loading. Similar to elastic modulus, the results of post-hoc testing showed shear modulus tended to decrease from deep to superficial layers of the annulus; however, no clear trends emerged in the radial direction (posterior versus anterior). In terms of the implications towards annulus function, a similar case to the normal loading situation may be made that this finding is functionally beneficial. Increased deformation in the outer layers may also lead to increase shear between layers. If this is the case, a less stiff inter-lamellar matrix between more superficial layers of the annulus may be beneficial in resistance to damage.

Curiously, the shear modulus trend was not found to be consistent in the radial direction. Neither the posterior nor anterior region of the annulus was consistently more or less stiff with respect to shear compared to the opposite region. During maximum flexion, it may be expected that the level of shear is higher in the posterior region of the annulus compared to shear in the anterior region during maximum extension, and therefore it should be beneficial to have a less stiff shear modulus in the posterior region. This expectation was not consistent with the findings of this study.

5.7 CONCLUSIONS

This project contributes to our fundamental understanding of annulus tissue mechanics under normal biaxial loading and uniaxial shear loading. Elastic modulus was reported for both a single layer and bi-layer sample of annulus tissue. Shear modulus was reported for a bi-layer layer sample of annulus tissue. These values may potentially be incorporated to future numerical models exploring the mechanical behaviour of the intervertebral disc under unique loading scenarios. Regional variation in material properties of the annulus was explored, as was the effect of biaxial loading under both uneven and even peak strain targets for each of the orthogonal loading directions.

Beyond the obvious reporting of annulus material properties, this study provided insights into the mechanical structure and behaviour of porcine annulus tissue. Bi-layer samples generally had a slightly lower elastic modulus, although this difference was not statistically significant. One possible reason for this trend may have been a result of limitations in the material testing methods. Once removed from the intervertebral disc, the collagen fibers embedded within the layers of the annulus may have been less constrained. This lower level of constraint may have allowed the fibers to re-align themselves to a greater extent, therefore resulting in a stiffer material. In the bi-layer samples, the collagen appeared to be more constrained. This condition was determined to be more physiologically relevant, and future numerical models likely should use a bi-layer segment of annulus as the smallest functional annulus unit.

Finally, the toe region of the annulus was larger than expected. Traditionally, the annulus has been assumed to be linear elastic and has been modeled as such. This likely remains a good assumption; however, at low levels of strain, a more robust material model may be appropriate.

Chapter 6 - Changes in L4-L5 intervertebral disc peak strain location and magnitude between sitting and standing: A finite element study

6.1 INTRODUCTION

Chronic low back pain can be caused by a number of different reasons including tissue damage to bone, muscle, ligament, and tendon; however, the most prevalent cause of chronic low back pain is internal disruption of the intervertebral disc (Schwarzer et al. 1995). Approximately 40% of patients with chronic low back pain are diagnosed with a disc disruption (Schwarzer et al. 1995). The most common discs to become injured are the discs between L4-L5 vertebrae and the disc between L5-S1 vertebrae (Schwarzer et al. 1995).

Finite element models (FEM) can provide insight into clinical problems not easily available through traditional *in vivo* or *in vitro* experimentation. A particular strength of finite element modeling is the ability to predict not only peak load magnitude but also load distribution. This ability of finite element modeling is particularly useful for studying low back pain and injury since it has been previously stated that, "it is the concentration of force that causes injury and elicits pain" (Dolan and Adams 2001). Finite element models predict stress and strain distribution throughout a structure. Stress concentrations, which may lead to pain, have been reported in both the anterior and posterior annulus of the lumbar spine during *in-vitro* testing measured using needle pressure profilometry (Adams et al. 1996; McMillan et al. 1996; Adams et al. 2000).

This study further explores this concept using the higher resolution stress/strain distributions available through finite element modeling.

Intervertebral disc height loss throughout the day has been shown to result from both standing and sitting (Botsford et al. 1994; Paul and Helander 1995). Alternating between sitting and standing while working in an office has been shown to lessen the disc height loss throughout the day (Paul and Helander 1995). Increased axial compressive load applied to an intervertebral disc has been shown to have a near-linear relationship with increased intervertebral disc pressure (Berkson et al. 1979; Nachemson 1963) and height loss. Activities with greater compressive force cause decreased disc hydration (Claus et al. 2008), which is likely to cause lower intervertebral disc pressure. Therefore, intervertebral disc height loss is probably a combination of two separate mechanisms: an initial compressive force applied to the spinal column, and intervertebral pressure loss as a result of prolonged loading. A topic that has yet to be explored is: what is the result of intervertebral disc height loss on the load distribution in the annulus of the disc?

Determining the true joint center of rotation for a spinal segment has been a consistently debated topic in spine biomechanics. Creep in spinal segments has been shown to significantly affect both range of motion and neutral zone in flexion and extension testing of human cadaveric spine segments (Busscher et al 2011). Along with changes in range of motion and neutral zone it is likely the center of joint rotation for the spinal segment also changes with creep (Callaghan and McGill 2001b; Parkinson and Callaghan 2009). The combination of uncertainty in determining true joint center of rotation in modeling spine segments, and changes in joint center of rotation as a result of creep, raises the final topic to be explored in this study: what is the result of changes in joint center of rotation on the load distribution in the annulus of the disc?

6.2 PURPOSE

The purpose of this study was to determine the potential effects of prolonged sitting, prolonged standing, and a sit-stand cycle on strain magnitude in the intervertebral disc. Postural and load changes, disc height loss, and joint center of rotation migration have all been shown to be different between sitting and standing. As such, these four variables were controlled to determine their effects on intervertebral disc load magnitude.

6.3 HYPOTHESES

There were two main hypotheses for this study:

1) When compared to prolonged sitting, spine loading and posture associated with prolonged standing will result in lower peak strain magnitude.

   Rationale: Compressive forces may lead to increased pressure in the intervertebral disc nucleus, causing an increase in tension in the surrounding annulus. Lower magnitude compressive forces in the low back have been reported during standing compared to sitting (Callaghan and McGill 2001). Consequently, in the model, lower compressive force during standing will result in lower nucleus pressure, lower tension in the annulus, and ultimately lower peak strain.

   Lumbar flexion has been shown to increase over time during both prolonged sitting and prolonged standing (Sanchez-Zuriaga et al. 2010; Gregory and Callaghan 2008a), with a lower magnitude of increase during standing. Less lumbar flexion in standing may result in a deeper peak strain location within the annulus, since geometrically, a greater level of flexion will cause the greatest change in length for the most external or peripheral levels of the annulus.

2) Joint center of rotation migration to the posterior of the intervertebral disc will result in lower peak strain on the annulus.

   Rationale: Posterior migration of the joint center will result in less elongation of the annulus tissue on the posterior surface of the annulus during flexion, leading to lower peak strain.

6.4 METHODS

A finite element model (**Figure 6-1**) was developed for a C3-C4 porcine functional spinal unit (FSU). The model was created using the C3 and C4 vertebrae and endplates of a model previously described (Howarth 2011; Howarth et al. 2012; Karakolis et al. 2014). The vertebrae and endplate models were previously developed in our research group and therefore this study focused on the development of a refined intervertebral disc model within the FSU.

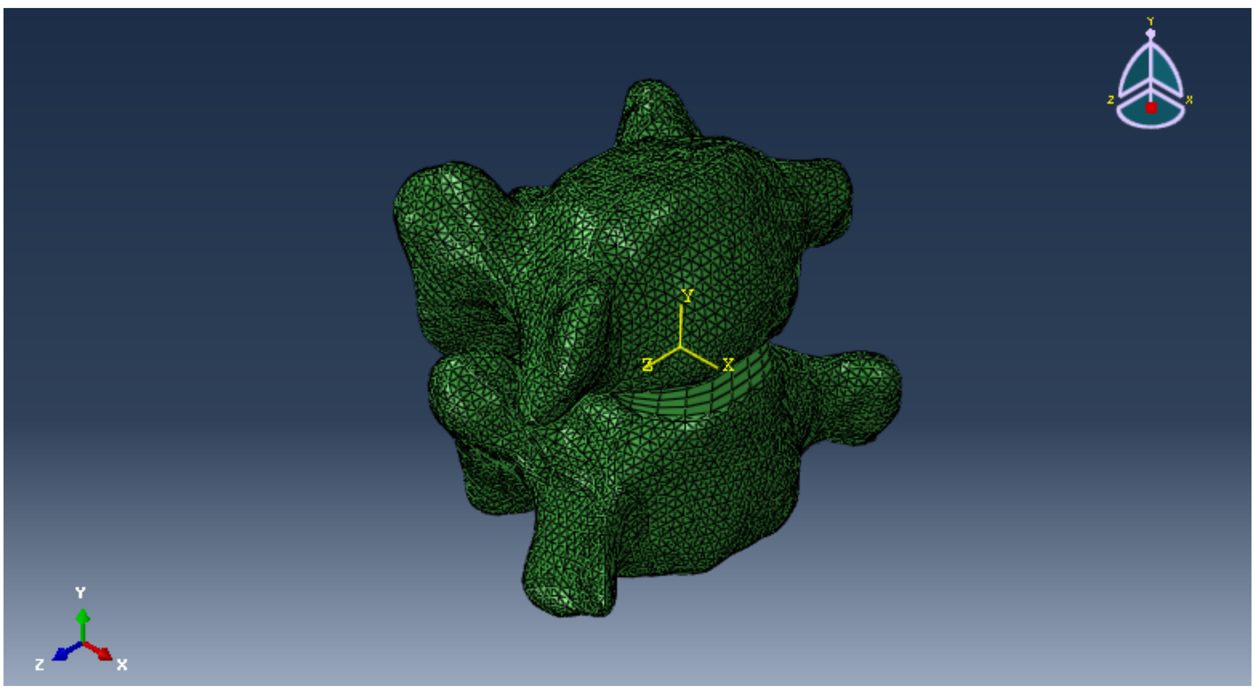


Figure 6-1: Finite Element Model of a C3-C4 porcine functional spinal unit

6.4.1 Vertebrae and endplates

Geometries of a C3 and C4 porcine vertebra were obtained from a series of scans using two white light scanners (StarCam FW-3R 3D, VX Technologies Inc., Calgary, AB, Canada). Each vertebra was sprayed with liquid developer (SKD-S2 Developer, Magnaflux, Glenview, IL, USA), prior to scanning, to enhance the contrast between the vertebrae and table surface. White dots fixed to the table surface were used to align point clouds generated from independent scans. Each vertebra was scanned in four orientations: lying on the inferior, superior, and anterior vertebral body surfaces, and with the spinous process mounted in black moulding clay. Point clouds from each pose were merged to create a final point cloud representing the vertebral geometry. The point clouds for each vertebra were then uploaded into a commercial software package (Geomagic Studio 9, Geomagic, Research Triangle Park, NC, USA), and surfaces consisting of triangular polygons were fit to the scanned vertebrae. Holes in the surfaces were patched, and the entire surface was smoothed using the software's built-in functions. The vertebral surfaces were then uploaded into a different commercial software package to create a mesh of the entire volume (Hypermesh 10, Altair Engineering, Troy, MI, USA). The volume inside each vertebral shell was meshed with four node tetrahedral elements (Howarth et al. 2013). The vertebrae were aligned to represent the neutral posture of an intact porcine C3-C4 FSU (Howarth et al. 2013). Sets of quadrilateral elements on the inferior surface of the superior vertebra, and on the superior surface of the inferior vertebra, were created to represent the endplates (Howarth 2011). Material properties were assigned to each volumetric and shell element (**Table 6-1**). Each material was modeled as linear, isotropic, and homogeneous with properties for the porcine spine taken from the literature (Kato et al. 1998; Teo et al. 2006; Kumaresan et al. 1999). The values selected for the literature were specifically chosen because each has already been used in spine finite element models previously (Kumaresan et al. 1999; Howarth et al. 2013). Contact between adjacent vertebrae was modeled as frictionless and non-linear (Chosa et al. 2004; El-Rich et al. 2009), with node-to-surface contact defined between cortical shell elements.

Table 6-1 – Element type and material properties for vertebrae and endplates. [1]Kato et al. 1998; [2]Teo et al. 2006; [3]Kumaresan et al. 1999.

Material	Element Type	Thickness (mm)	Modulus (MPa)	Poisson's Ratio
Cortical bone	Triangular Shell	0.45[1]	19,400[1]	0.34[1]
Trabecular bone	Tetrahedral	N/A	229[2]	0.30[3]
Endplate	Quadrilateral Shell	0.45	50[3]	0.40[3]

The vertebrae models have been verified and validated under shear loading, and a sensitivity analysis has been completed (Karakolis et al. 2014). Under shear loading, this model has been shown to be accurate within less than 2% force error, when compared to experimental work.

6.4.2 Intervertebral disc

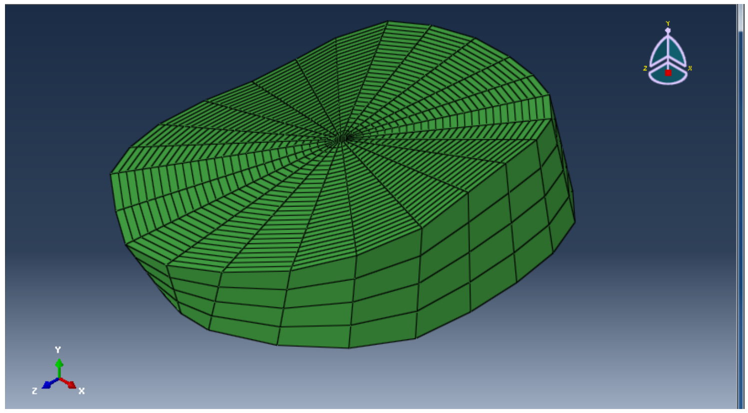
Geometry for the intervertebral disc was obtained from a series of two scans using a 3D laser scanner (StarCam FW-3R 3D, VX Technologies Inc., Calgary, AB, Canada). The scans were taken of the intervertebral disc of a C3/C4 porcine FSU mounted in a material testing system similar to that previously described (Howarth and Callaghan 2013). Unlike the method previously described, instead of mounting a complete osteoligamentous FSU structure, posterior elements of the FSU were removed in order to have a clear sightline to the posterior surface of the annulus. Effectively, the reduce structure FSU mounted consisted of only a superior and inferior vertebral body and the intervertebral disc. A neutral posture for the mounted reduced FSU was found using a method of flexing and extending the FSU in a material testing system while measuring torque to find the point of zero torque, similar to that previously described by Callaghan and McGill (2001). Following determination of the neutral posture, a scan of the anterior surface of the disc was taken. The specimen was then removed from the material testing system and rotated 180 degrees before being re-mounted. Next, a scan of the posterior surface of the annulus was taken. A cubic spline interpolation was used to interpolate the surface geometries of the lateral sides of the annulus not scanned.

The annulus was modeled as a series of 8-node brick elements arranged to form concentric layers to represent the lamellar structure of the annulus (**Figure 6-2**). Each layer in the model represented a functional annular unit, comprised of two adjacent lamellae and an inter-lamellar matrix. The thickness of each layer was approximately 0.36 mm, based on the value reported in Chapter 4 of this document. Due to the irregular geometry of the outer surface of the annulus, regional variation in thickness was unavoidable. Previous literature reports the human annulus structure to be composed of 15-25 layers (Cassidy et al. 1989; Marchand and Ahmed 1990). The number of layers selected for the disc model used in this study was 20 layers. Twenty single layers translate to 10 bi-layers (or functional annular units). Therefore, elements in the outermost 10 layers of the modeled disc structure were assigned the annulus material model. All remaining elements in the disc structure were assigned the nucleus material model.

The material model for annulus tissue was linear elastic and isotropic. The elastic modulus was 0.8 MPa and the Poisson's ratio was 0.5. The elastic modulus was selected because it was the mid range value for a bi-layer sample of annulus tissue reported in Chapter 5.

The nucleus pulposus was modeled using incompressible fluid elements with a bulk modulus of elasticity (k) of 1720 MPa. This value has been previously used for modeling the nucleus by Panzer and Cronin (2009) and was first reported by Yang and Kish (1988).

A



B

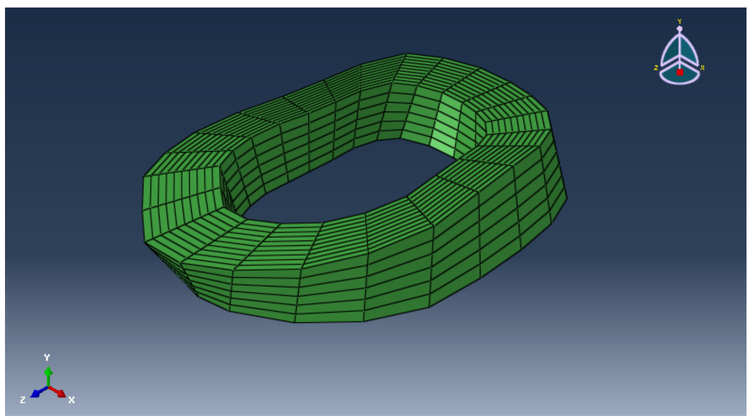


Figure 6-2 – A) Finite element representation of the entire disc structure (annulus + nucleus)
B) Finite element representation of the Refined Annulus created for the sensitivity analysis

6.4.3 Verification, validation, and sensitivity analysis

Verification, validation, and sensitivity were conducted following a method previously described by Jones and Wilcox (2008) and demonstrated by Karakolis et al. (2014).

Mesh verification for the intervertebral disc was accomplished through a convergence study. Mesh refinement consisted of approximately doubling the total number of disc elements for each level of refinement. Mesh refinement continued until peak surface strain change between consecutive mesh refinement levels was below one percent. An additional mesh refinement step was also completed where the annulus was refined once again after the convergence criteria was met in order to ensure true convergence was found. Two combinations of posture and loading boundary conditions were used (**Table 6-2**). Each combination was selected to represent and typical loading scenario for seated and standing work respectively. Typical loading scenarios were selected based upon the loading values reported in Chapter 4 of this thesis document.

Table 6-2: Boundary conditions imposed during mesh verification study and sensitivity analysis. Conditions were selected to represent a typical sitting and a typical standing posture.

	Sitting	Standing
L4/L5 Flexion (degrees)	6	0
Compressive Load (N)	510	550
Anterior Shear Load (N)	100	25

Validation was accomplished using a comparison of model disc height loss and experimental disc height loss previously presented by Callaghan and McGill (1995) for static compressive loads of 5090 N, 6270 N, and 7450 N. Boundary conditions were imposed to load the model in a manner representative of *in vitro* loading conducted previously (Callaghan and McGill 1995).

A material property sensitivity analysis was conducted following the framework previously described (Karakolis et al. 2014). Elastic modulus for the annulus layer elements was varied between the minimum and maximum elastic moduli reported in Chapter 4 of this document. Boundary conditions for the material property sensitivity analysis were the same as those for mesh verification (**Table 6-2**).

6.4.4 Loading

During loading, the FSU model always began in an unloaded neutral posture. First, an encastre boundary condition was used on a set of nodes on the inferior surface of the C4 vertebrae to hold the C4 vertebrae in place throughout the simulation. A node set on the superior surface of the C3 vertebrae was selected to adjust the flexion/extension posture and compressive and shear direction loads. These loads and postures were selected based on the results presented in Chapter 3 of this document (**Table 6-3**). In Chapter 3, L4/L5 joint loading was calculated and therefore this value could directly be used as a model input. For L4/L5 joint angle, the lumbar flexion angle reported in Chapter 3 was divided equally among the intervertebral discs of the lumbar spine (L1/L2-L4/L5). The assumption that lumbar flexion angle can be evenly divided between discs is based on the work of De Carvalho et al. (2010) showing that while sitting in an automobile seat, the average angle between vertebrae was not statistically different from the L1-L5 vertebrae.

Table 6-3: Boundary conditions for: the sitting period of the sit-only condition in Chapter 3; the sitting period in the sit-stand condition; the standing period in the stand only condition; and the standing period in the sit-stand condition.

	Sit (Sit Only)	Sit (Sit-Stand)	Stand (Stand Only)	Stand (Sit-Stand)
L4/L5 Flexion (degrees)	5.5	4.2	-0.6	-1.2
Compressive Load (N)	447.35	453.69	513.30	494.30
Ant Shear Load (N)	106.51	82.70	-13.85	-23.95

A series of simulations were run to determine the effect of varying degrees of disc height loss associated with prolonged static postures. Disc height loss simulations were: 0 mm loss, 0.5 mm loss, and 1 mm loss. The 1 mm disc height loss was selected based upon spinal shrinkage values reported during a nine-hour workday by Paul and Helander (1995).

Multiple models were created for a series of simulations to determine the effect of migration of the joint center of rotation. Joint center of rotation was varied by increments of 2.5 mm in both the anterior and posterior direction for only the sitting boundary conditions. Schmidt et al. (2008) reported that joint center of rotation can vary depending on the direction and magnitude of the moment applied to the functional spinal unit. For relatively small moments (1.5 Nm) the center of rotation is in the center of the disc. Under a large moment (7.5 Nm) the center of rotation can migrate up to 8 mm from the center of the disc in the anterior and posterior directions, for flexion and extension respectively. 2.5 Nm was selected for the present study as a scaled distance to the approximate moment during sitting. **Tables 6-4** and **6-5** contain a complete summary off all the simulations conducted.

Table 6-4: Summary of all disc height loss simulations

Disc Height Loss (mm)	Boundary Conditions
0	Sit (Sit Only)
	Sit (Sit-Stand)
	Stand (Stand Only)
	Stand (Sit-Stand)
0.5	Sit (Sit Only)
	Sit (Sit-Stand)
	Stand (Stand Only)
	Stand (Sit-Stand)
1	Sit (Sit Only)
	Sit (Sit-Stand)
	Stand (Stand Only)
	Stand (Sit-Stand)

Table 6-5: Summary of all joint center simulations

Joint Center of Rotation (mm; + is anterior)	
-2.5	Sit (Sit Only)
	Sit (Sit-Stand)
0	Sit (Sit Only)
	Sit (Sit-Stand)
2.5	Sit (Sit Only)
	Sit (Sit-Stand)

6.5 RESULTS

In this section, the results of the verification, validation, and sensitivity studies will be presented in addition to the results of the sit versus stand versus sit-stand loading study.

6.5.1 Verification

A total of three meshes were created, with each mesh containing a larger number of smaller elements than the previous. Mesh convergence was found between meshes 2 and 3 for both the typical sitting and typical standing boundary conditions (**Table 6-6**). Mesh 3 was selected for all simulations.

Table 6-6: Summary Results for Mesh Convergence Study

	Total Disc Elements	Annulus Elements	Nucleus Elements	Peak Strain (Standing)	% Change	Peak Strain (Sitting)	% Change
Mesh 1	672	280	392	0.0735	-	0.0629	-
Mesh 2	1344	560	784	0.0806	9.7	0.0690	9.7
Mesh 3	4032	1680	2352	0.0813	0.8	0.0696	0.9
Mesh 4	7392	5040	2352	0.0815	0.2	0.0697	0.2

6.5.2 Validation

Figures 6-3 and **6-4** show force displacement curves for a previous experimental study and the FE model presented in this study. Both curves illustrate a linear relationship between force and displacement. **Table 6-7** compares experimentally reported displacement to model displacement.

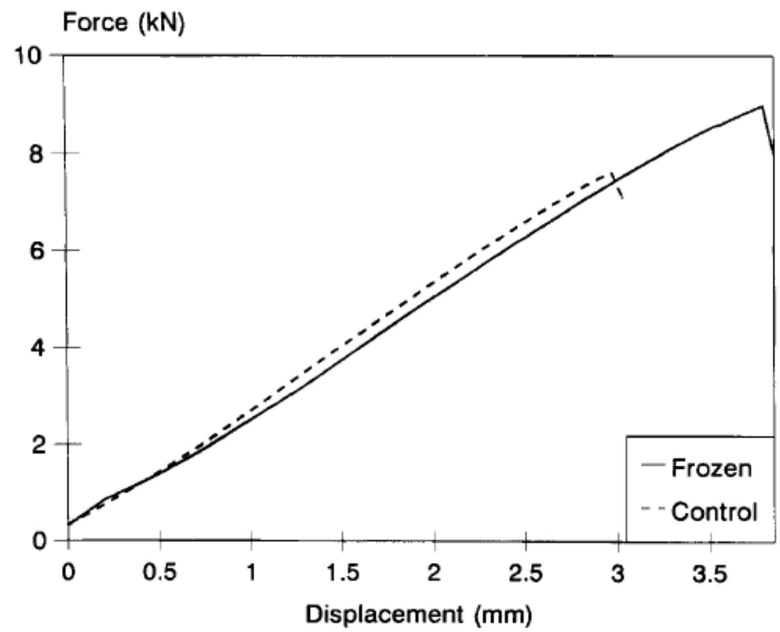


Figure 6-3: Typical Force versus Displacement curve presented by Callaghan and McGill (1995) for a porcine functional spinal unit loaded under compression in vitro.

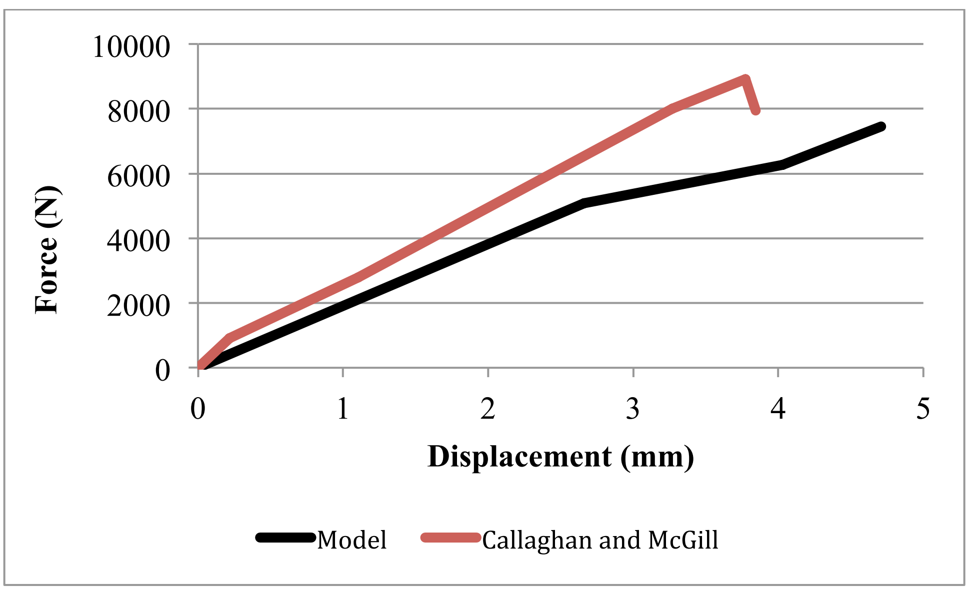


Figure 6-4: Force versus Displacement curves for the FE model presented in this study, loaded with boundary conditions to simulate the Callaghan and McGill (1995) study results plus and minus one standard deviation.

Table 6-7: Previously reported experimental loading (in vitro) height loss associated with loading and the corresponding simulated height loss using the FE model.

Load (N)	Height Loss - Experimental (mm)	Height Loss - Model (mm)
5090	2.26	2.66
6270	3.36	4.03
7450	4.36	4.71

6.5.3 Sensitivity

Peak strain changed during both the sitting and standing conditions for each elastic modulus (**Table 6-8**). Peak strain ranged from a low of 0.0481 for the stiffest elastic modulus (1.4 MPa) in the sitting condition to a high of 0.1530 for the least stiff elastic modulus (0.2 MPa) in the standing condition.

Table 6-8: Peak strain values for changing elastic modulus and boundary conditions.

Boundary Conditions	Elastic Modulus (MPa)	Peak Strain
Sit	0.2	0.1350
	0.8	0.0696
	1.4	0.0481
Stand	0.2	0.1530
	0.8	0.0813
	1.4	0.0585

6.5.4 Experimental Loading Simulations

As expected due to the difference in joint positioning, peak strain was consistently higher for all sitting conditions when compared to peak strain during the standing conditions (**Figure 6-5**). Interestingly, the combination of sit-stand altered the strain responses when compared to the postures during isolated sitting and standing (**Figure 6-6**). Peak strain for sitting during sit only was consistently higher than the corresponding sitting during sit-stand for all disc height loss levels. For zero disc height loss, peak strain for standing during stand only was lower than peak strain for standing during sit-strand. However, this trend was reversed for both the 0.5 mm and 1.0 mm levels of disc height loss with higher strains present in isolated standing. Disc height lost had a much larger affect on peak strain at the 1.0 mm level than the 0.5 mm level, when compared to the zero disc height lost condition.

A
B
C
D

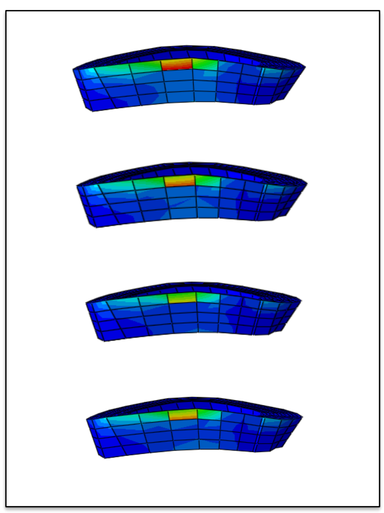


Figure 6-5: Strain distribution on the posterior surface of the annulus for the simulated conditions: A) Sit during Sit-Only; B) Sit during Sit-Stand; C) Stand during Stand Only; and D) Stand during Sit-Stand

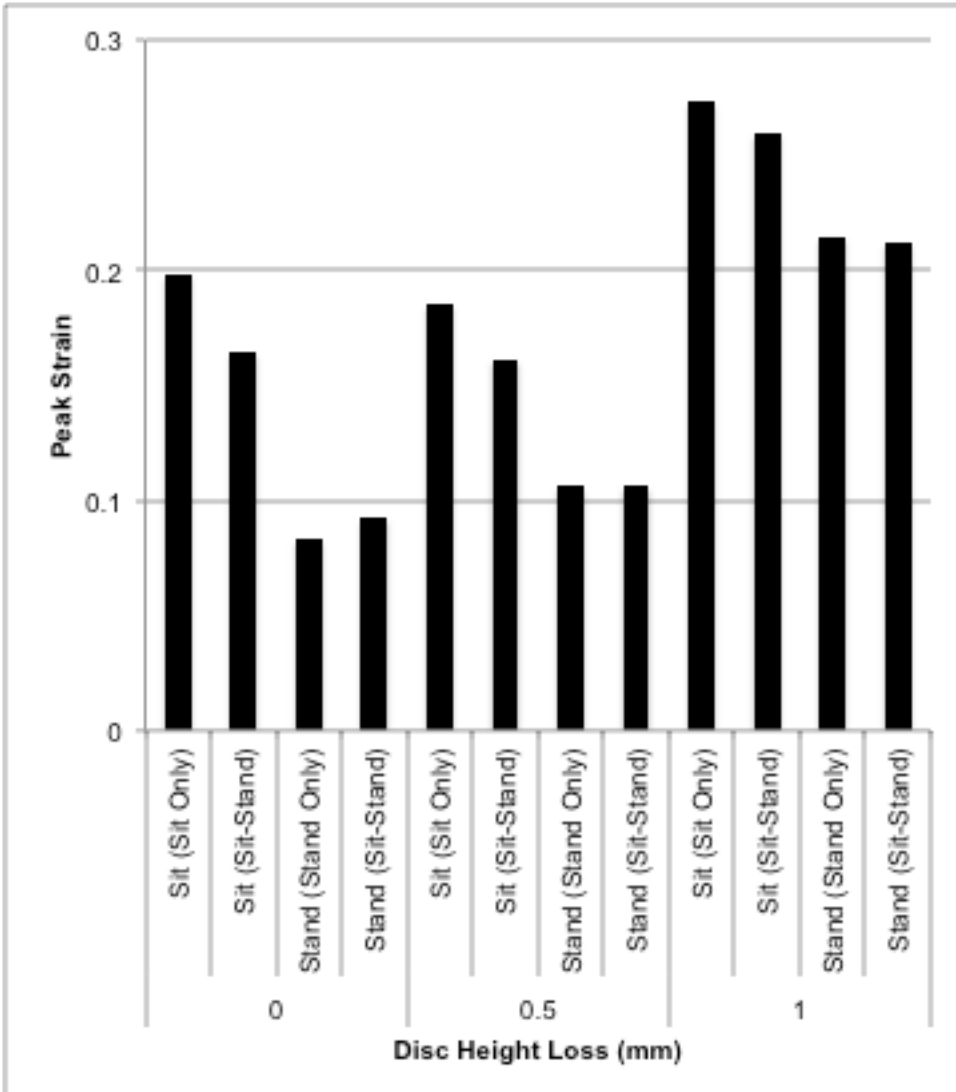


Figure 6-6: Peak strain determined for each combination of boundary conditions and levels of disc height loss.

Changing the joint center of rotation had minimal affect on the peak strain (**Figure 6-7**). The trend between sitting during sit only and sitting during sit-stand remained constant as well.

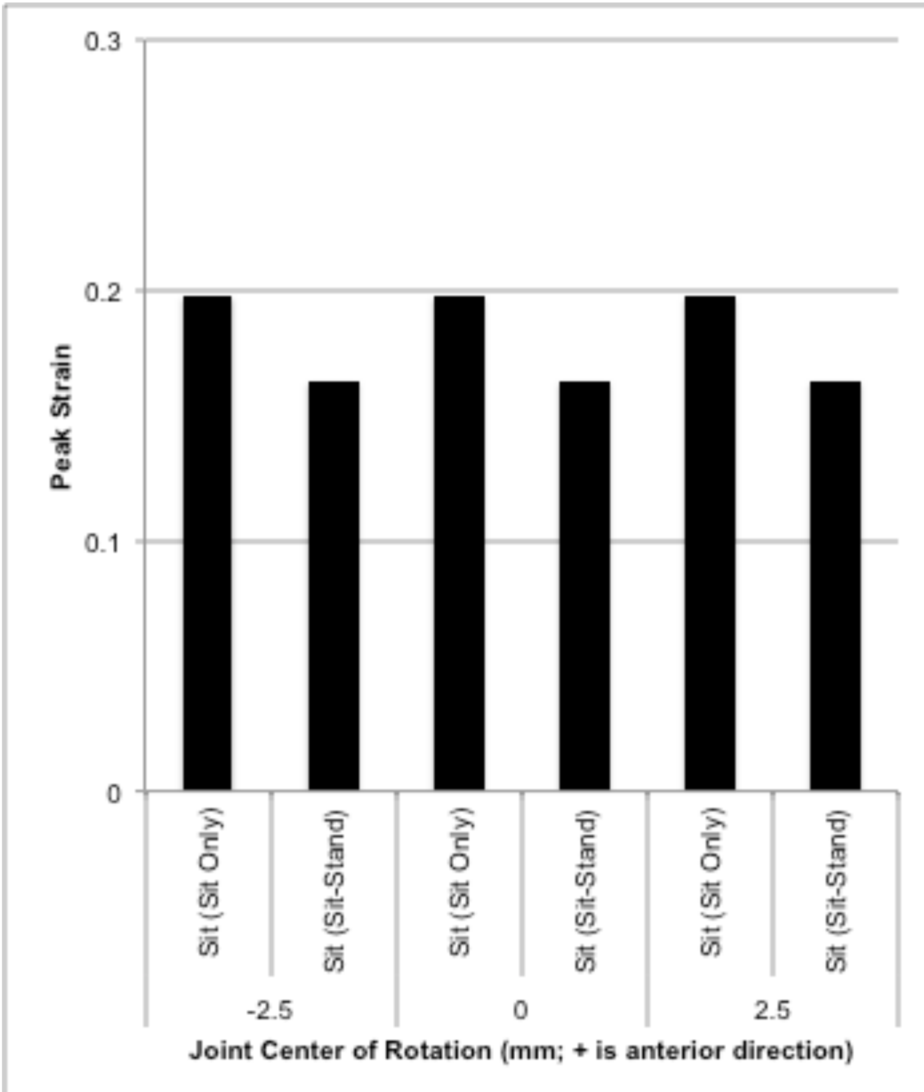


Figure 6-7: Peak strain determined for each combination of boundary conditions and joint center.

6.6 DISCUSSION

6.6.1 Verification, validation, and sensitivity analysis

Peak strain convergence was reached relatively quickly with relatively few elements in the structure of the intervertebral disc. Although convergence was met, based on the criteria established by Kotha et al. (2004) for a biomechanical model, an attempt was made to include even more elements in the disc in order to obtain a higher resolution for the locations of the peak strains. This attempt failed due to limitations in the meshing algorithm which caused elements that were either too small or had zero volume. This too small or zero volume error prevented the solver (ABAQUS) from generating a solution for a mesh more sensitive than the one used, however since convergence was achieved between Mesh 2 and 3, Mesh 3 was deemed an acceptable model for evaluating the biomechanical responses to the joint conditions present in Sit-Stand.

The comparisons made to *in vivo* experimental data during the validation portion of this study compared the numerically derived results to the fresh specimen results presented by Callaghan and McGill (1995). The model constantly generated results with a greater amount of disc height loss, when compared to the experiment. Callaghan and McGill (1995) also presented frozen/defrosted specimen results in their study in addition to the fresh specimen results. Frozen specimen were found to fail at a higher compressive load, although it is unclear whether or not this higher compressive load is associated with a corresponding higher level of disc height loss. It must be noted that the material tested in Chapter 4 to obtain the elastic modulus used to model the material in the finite element model was also frozen/defrosted tissue. Perhaps this potential small change in tissue properties after freezing could explain some of the small discrepancy between the model predicted and experimental results.

With respects to the material model used, experimental results show that a significant toe region exists during mechanical loading of annulus tissue (**Appendix D**). This toe region was not incorporated into the linear elastic material model used for the annulus tissue. Although the model showed good agreement with previously reported experimental results, this limitation must still be considered when interpreting any future model results.

6.6.2 Experimental Loading Simulations

Sitting consistently produced higher levels of peak strain than standing. This result confirms Hypothesis 1 of this study. Sitting did have a greater angle of lumbar flexion in the boundary conditions imposed in this model, and the increased flexion resulted in a higher level of 'baseline' strain on the annulus even before compressive and shear forces were applied to the model. Although both standing simulations had a slightly higher level of compressive force applied, the amount of shear force was lower for both standing simulations than both sitting simulations. The tradeoff between shear and compressive force with respect to peak annulus strain is not entirely clear. In context of the *in vivo* literature examining functional spinal unit joint injuries, low-level compressive loading combined with repetitive flexion has been shown to induce internal disc disruptions and disc herniation (Parkinson and Callaghan 2009; Tampier et al. 2007; Drake et al. 2005);

however, repetitive shear loading has been shown more likely to cause spondylitic fracture (Howarth and Callaghan 2013; Howarth 2011) instead of disc disruption.

Initial disc height loss had a very drastic affect on peak strain. Anecdotally, a noticeable level of bulge was observed in the disc between the steps of implementing the disc height loss and applying the load. This bulge resulted in a higher level of strain on the disc before the simulation even applied the compressive and shear loads, and this explains at least part of the drastic increase in peak strain. In the context of working in a sit-stand paradigm, the disc height loss examined in this experiment was selected based upon observed levels of disc height loss for office workers in the field (Paul and Helander 1995). Therefore, though the boundary conditions used to simulate sit only and sit-stand did not result in considerably different magnitudes of peak strain, changing only the boundary conditions may not have been a fair comparison. A more fair comparison may be to compare the different boundary conditions (sit only and sitting during sit-stand) across disc height loss conditions. The difference between in peak strain for sitting during sit-stand at 0 mm or 5 mm disc height loss and sit only at 1 mm disc height loss are far more drastic (**Figure 6-5**). This indicates sit only may have even higher potential to cause injury, when compared to sitting in sit-stand, then the boundary conditions alone would indicate.

Joint center of rotation migration had nearly no affect on peak strain. This is in contrast to the second Hypothesis of this study. It was expected that migrating the joint center in the anterior direction would result in a higher level of strain on the posterior of the annulus as a result of a larger elongation of that surface during flexion. Perhaps the ±2.5 mm migrations were simply too small to cause a noticeable difference in initial strain in the annulus before loading. Based on the work of Schmidt et al. (2008), the joint center of rotation does have the potential to migrate further in the anterior direction than the 2.5 mm used in this study; however, the increased distance of migration reported by Schmidt et al. (2008) was associated with higher magnitudes of loading on the functional spinal unit. Therefore, it may be possible that while performing tasks that result in higher magnitude loading on the spine, joint center of rotation migration during flexion may still be an issue that needs to be explored. Nonetheless, the present study does still provide the first piece of evidence that shows during prolonged sitting and prolonged standing tasks, and while working in a sit-stand paradigm, joint rotation migration that results from flexion and tissue creep is likely not a key mechanism related to injury.

For the static FE Model used in the present study, strains were largest on the superficial surface of the annulus. With respect to injuries that may be caused by prolonged static postures such as sitting and standing, this indicates injuries are likely initiated in the superficial layers of the annulus and propagate inward. This injury mechanism differs from the injury mechanism demonstrated previously. Veres et al. (2008) describe the injuries caused by dynamic pressurization of the nucleus as initiating in the deeper layers of the annulus and progressing outward. These results indicate injury mechanism may differ between static and dynamic loading scenarios.

When evaluating *in vivo* loading through finite element modeling, limitations exist that are similar to those that exist during *in vitro* mechanical testing of tissues that have the same goal to represent and evaluate *in vivo* loading. A specific potential limitation to this model is the porcine geometry and material properties used to create the FSU. Previous work has demonstrated the porcine cervical spine can be used as an acceptable surrogate for the human lumbar spine (Yingling et al. 1999) during mechanical testing. The Yingling et al. (1999) study compared function, anatomy, and geometry between human lumbar spine and porcine cervical spine. Since the same anatomy and geometries used during mechanical testing were the basis of the FE model, Yingling's same conclusions should hold for the FE modeling performed. With respect to annulus tissue specifically, this tissue has not been validated as an acceptable human surrogate. However, there still remains a body of literature focused on the mechanical testing (Gregory and Callaghan 2011a; 2011b) and dissection of porcine annulus tissue (Tampier 2006; Tampier et al. 2007) to understand the mechanisms associated with human disc herniation. Finally, the focus of the FE analyses was to compare the relative IVD strain changes between the working postures (sitting, standing, and sit-stand); therefore, since less focus was placed on the absolute values for translation to human disc strains the model was deemed feasible to evaluate relative comparisons.

6.7 CONCLUSIONS

Based on the results of the verification, validation and sensitivity study, this model was concluded to be a valid representation of the porcine intervertebral FSU, and specifically the disc model produced reasonable agreement with experimental work in levels of disc height loss. The sensitivity analysis did reveal that the model is somewhat sensitive to changes of the material properties, even changes within the range of elastic modulus reported in Chapter 4. This limitation of the model must be considered when evaluating the validity of any results derived from the model.

In general, sitting postures and loading resulted in higher levels of peak strain in the annulus of the intervertebral disc. When comparing between sitting while working in a sitting only paradigm and sitting while working in a sit-stand paradigm, sitting only consistently resulted in slightly higher levels of peak strain. When comparing between standing while working in a standing only paradigm and standing while working in a sit-stand paradigm, the results were mixed. Depending on disc height, either paradigm could produce higher levels of peak strain.

Disc height loss has the potential to cause considerably higher levels of peak strain in the annulus. A disc height loss of as little as one millimeter may potentially increase annulus peak strain between 5-10 percent. Since the disc height loss selected for this study was based upon the disc height loss observed while working in a sit-only paradigm compared to a sit-stand paradigm, this change in peak strain associated with disc height loss may be important from an injury mechanism prospective. Disc height loss results in increased strain on the disc. Therefore although the changes in boundary conditions between sit only and sit-stand do not result in drastic changes in peak strain, the disc height loss associated with prolonged sitting do result in considerably higher magnitude peak strain. For this reason, working in a sit-stand paradigm is likely beneficial from an injury prevention perspective.

Finally, changes in the joint center of rotation for the L4/L5 joint did not appear to have a noticeable affect on the annulus peak strain. Therefore, changes in joint center of rotation associated with the magnitude of joint loading during sitting and standing is not a likely contributor to injury risk.

Chapter 7 – General Discussion and Conclusions

The results of the sit-stand review and three studies presented in this thesis demonstrate a thorough examination of the potential benefits and drawbacks of working in a sit-stand paradigm while performing office work. Study 1 examined the *in vivo* postures adopted by university-aged students while working in a sit only, standing only, and sit-stand paradigm. Discomfort and productivity were also monitored throughout the study. The biomechanical results of the study were used to drive the finite element model developed in Study 3 (Chapter 6).

Study 2 (Parts A and B) did not directly examine the sit-stand paradigm; however, the results reported for the elastic moduli of the annulus tissue were crucial in creating the finite element model used in Study 3 to further examine sit-stand work. Additionally, the insights into the mechanical behaviour and structure of the annulus gained in Study 2 (in particular Study 2-A) benefited in creating an improved model, representative of the annulus.

Before examining the combined conclusions of each study further, it is beneficial to revisit the specific hypothesis presented.

7.1 HYPOTHESIS REVISITED

Study 1 – A comparison of lumbar spine kinematics and kinetics during simulated sit-stand office work with prolonged sitting and prolonged standing office work

(1) Sit-stand work will positively influence both seated and standing lumbar spine mechanics when compared to either posture performed in isolation.

DECISION: Not Accepted. Although sit-stand work was shown to consistently reduce lumbar flexion during the sitting time periods when compared to the analogous time periods during sit only work, this difference was not statistically significant. Furthermore, no clear trends or statistically significant differences immerged when examining trunk posture or compressive and shear loading of the lumbar spine.

(2) Sit-stand work will reduce low back discomfort when compared to either posture performed in isolation.

DECISION: Not Accepted. Sit-stand work showed the potential to reduce discomfort through considerable levels of discomfort 'recovery' immediately following a posture change. Unfortunately, the 'recovery' did not seem to be permanent as discomfort increased more rapidly when a sitting posture was adopted again. No significant differences were found when discomfort for an entire sit-stand cycle was collapsed and compared to equivalent time periods for sit only and stand only.

(3) Sit-stand work will not reduce productivity when compared to either posture performed in isolation.

DECISION: Accepted. Sit-stand work did significantly reduce any of the productivity measures. Although typing productivity was slightly lower in the sit-stand condition, mousing productivity was slightly higher. Beyond no statistical significant differences, for practical purposes all productivity measures were no different between conditions.

Study 2 – Determining material properties of the porcine intervertebral disc

Part A

1) For both single layer and bi-layer samples, loading magnitude will not have a significant effect on elastic modulus.

   DECISION: Rejected. Peak strain had a statistically significant effect in the elastic modulus calculated in both orthogonal directions for the bi-layer samples. Peak strain also had a statistically significant effect in the circumferential direction for the single layer samples; however, no significant difference was found in the longitudinal direction.

2) For both single layer and bi-layer samples, elastic modulus determined using equal orthogonal loads during biaxial loading will be significantly different from elastic modulus determined using unequal orthogonal loads.

   DECISION: Not Accepted. In the circumferential direction, there was no statistically significant difference in calculated elastic modulus between uneven and even orthogonal peak loading conditions. In the longitudinal direction, there was a statistically significant difference in calculated elastic modulus between uneven and even loading. These results held true for both the single layer and bi-axial tissue samples.

3) For both single layer and bi-layer samples, the region of the annulus from which the tissue sample was obtained will impact elastic modulus.

   DECISION: Accepted. The region of the annulus from which the single layer and biaxial samples were obtained was the only independent factor that had consistently a significant effect on elastic modulus. Location was statistically significant in both the circumferential and longitudinal direction for both single and bi-layer samples.

Part B

1) The shear modulus of the inter-lamellar matrix will be impacted by the radial location in the annulus and depth of the tissue sample.

   DECISION: Accepted. Similar to findings for Hypothesis 3) of Study 2, the region of the annulus from which the single layer and biaxial samples were obtained was a statistically significant factor.

2) Loading magnitude will have a significant effect on the shear modulus.

   DECISION: Accepted. Peak strain had a significant effect on the shear modulus calculated.

Study 3 – Changes in L4-L5 intervertebral disc peak strain location and magnitude between sitting and standing: A finite element study

1) When compared to prolonged sitting, spine loading and posture associated with prolonged standing will result in lower peak strain magnitude and a peak strain location located deeper within the annulus.

   DECISION: Accepted. Sitting consistently produced higher levels of peak strain than standing. The sitting boundary condition had a greater angle of lumbar flexion imposed on the model. The increased flexion resulted in a higher level of 'baseline' strain on the annulus even before compressive and shear forces were applied to the model. This resulted in higher peak strain for the sitting condition compared to the standing condition.

2) Joint center of rotation migration to the posterior of the intervertebral disc will result in lower peak strain on the annulus

   DECISION: Rejected. Joint center of rotation migration had nearly no affect on peak strain. It was expected that migrating the joint center in the anterior direction would result in a higher level of strain on the posterior of the annulus as a result of a larger elongation of that surface during flexion. Perhaps the ±2.5 mm migrations were simply too small to cause a noticeable difference in initial strain in the annulus before loading.

7.2 COMBINED RESULTS AND IMPLICATIONS ON SIT-STAND

The results of each individual study alone in this thesis add multiple contributions to our understanding of the potential causes of discomfort and injury mechanisms associated with sitting and standing. However, the principle contribution of this thesis is to begin filling some of the gaps in the literature around working in a sit-stand paradigm in an office environment.

The targeted literature review (Chapter 3) is the first main contribution of this thesis. By reviewing the entire current literature specific to the use of sit-stand workstations, the knowledge already existing in the field was consolidated. The review concluded that sit-stand workstations likely have the potential to reduce worker discomfort and do not reduce worker productivity. Beyond those main conclusions, the review also highlighted the lack of literature concerning the potential for sit-stand workstations for reducing injury.

The *in vivo* sit-stand study (Chapter 4) not only confirmed the conclusions in the sit-stand review by examining discomfort and worker productivity, but this study also began to explore potential injury mechanisms known to be associated with prolonged sitting and prolonged standing. Chapter 4 is also the first known study to examine the sit-stand paradigm in the same manner as prolonged sitting and prolonged standing have been examined previously. Although the *in vivo* study did show slightly lower lumbar flexion during sitting in a sit-stand paradigm compared to prolonged sitting, a potential benefit in preventing injury, the study was not able to conclusively show that working in a sit-stand paradigm is beneficial from an injury perspective beyond simply reducing the total time sitting while working.

Study 2 (Chapter 5) was a necessary study to better understand the mechanics of the annulus tissue that composes the intervertebral disc. In order to model this tissue to understand the strain magnitude in the disc during sitting and standing (Chapter 6 – Study 3), a comprehensive disc model needed to be created. Study 2 found that annulus material properties varied by region of the annulus from which they were obtained. The study also found that when material testing annulus tissue, the means by which the boundary conditions were applied to the tissue affected the derived materials properties. Specifically, Study 2 showed that during mechanical testing, the boundary conditions imposed on an individual layer of annulus tissue might not be representative of the boundary conditions on the tissue in the disc. This consequently affects how the annulus should be modeled numerically using results of this study. In simplest terms, the main finding of the study was the conclusion that modeling the disc in bi-layer, Functional Annular Units, is likely the most appropriate method of modeling the annulus.

Study 3 (Chapter 6) produced the most conclusive evidence that working in a sit-stand paradigm is beneficial from an injury perspective beyond simply reducing the total amount of time sitting throughout the day. The study showed that the boundary conditions imposed on the L4/L5 joint during periods of sitting while working in a sit-stand paradigm result in lower peak strain when compared to sitting while working in a sit only paradigm. Furthermore, the disc height loss associated with prolonged sitting causes an even more drastic increase in peak strain in the disc. Avoiding this increase in peak strain in the disc associated with disc height loss may be the most beneficial aspect of working in a sit-stand paradigm.

Finally, the combined results of all the studies presented lend some insight into the similarities and differences between the injury mechanisms potentially associated with prolonged sitting and prolonged standing. Lumbar flexion seems to drive annular strain to a greater extent when compared to compression. This is evident in that peak annular strain is higher in sitting, since sitting has a higher level of flexion yet lower level of compression compared to standing. Higher peak strain in sitting likely results in higher levels of annular tissue creep during prolonged sitting. Tissue creep is likely the mechanism driving the general trend of increasing lumbar flexion for prolonged sitting found in Study 1 of this thesis. Alternating between sitting and standing may reduce the level of creep over time, and therefore be advantageous in preventing injuries.

7.3 FUTURE WORK

In continuation of the work completed for this thesis, future work should explore the effect of altering the ratio between sitting and standing times in the sit-stand paradigm. Although this thesis shows working at a sit-stand workstation has the potential to reduce discomfort and perhaps even prevent injury, the 15 to 5 minute ratio used does not seem to take full advantage of the potential.

Job rotation can be considered similar to sit-stand in the sense that the goal of job rotation is generally to adjust postures and loading assumed during the workday. However, unlike job rotation, sit-stand work does not generally involve changing the task being performed. Job rotation has been shown to have mixed results in terms of preventing fatigue in the workplace (Lugar et al. 2004). With that in mind, sit-stand work in future can be studied in conjunction with job rotation to determine the combined strengths and limitations of each strategy.

Additional work can also be done to refine the material testing methods used to determine the elastic modulus of the annulus. Of specific interest will be to develop a method that addresses the issue of collagen fiber re-arrangement that may not be representative of the physiological environment that annulus tissue experiences.

Finally, further model refinement must continue in concurrence with the updated values determined using the refined material testing methods. This continued model refinement will ensure the validity of the model continues to increase.

7.4 CONCLUSION

Beyond simply reporting the values of elastic and shear modulus of porcine annulus tissue that may be used in future intervertebral disc numerical models, this thesis demonstrated that working in a sit-stand paradigm has the potential to reduce discomfort and possibly prevent injury when compared to sit only and stand only work. Altered joint kinematics and kinetics resulted in lower peak strains in the disc when working in a sit-stand paradigm. Peak disc strain was most drastically reduced when disc height loss, at magnitudes associated with prolonged sitting work, was evident. A reduction in peak disc strain is likely beneficial in injury prevention. Finally, it was found that the reduced discomfort and potential injury prevention gained from working at a sit-stand workstation does not likely come at the cost of decreased worker productivity.

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APPENDIX A – Characteristics of Studies Included in Review

Characteristics of included studies

Nerhood 1994	
Methods	Intervention/No Control
Participants	Subjects: Number/gender of subjects not reported Inclusion: UPS office employees Exclusion: N/A
Sit-stand Paradigm	Participants were provided with a counterbalance height adjustable workstation Training was provided
Outcome Measures	Discomfort - Local discomfort questionnaire Absenteeism
Notes	Statistical analysis was unclear Study was conducted in the field
Paul 1995a	
Methods	Two Interventions/No control
Participants	Subjects: 13 VDT operators (10 healthy, age: 34.6, 3 with a spinal disorder, age: 48.
Sit-stand Paradigm	2 Conditions: 1) Stand for 30 minutes four times per day 2) Stand for 15 minutes eight times per day
Outcome Measures	Spinal shrinkage
Notes	Study was conducted in a laboratory setting
Paul 1995b	(foot swelling)
Methods	Within Subject Design
Participants	Subjects: 6 office employees (5 female, 1 male, age: 39.0)
Sit-stand Paradigm	2 Conditions: 1) Sit only work 2) Sit to stand work (stand 15 minutes every hour)
Outcome Measures	Foot volume

Notes	Conditions were not presented in random order Study was conducted in the field
Paul 1995c	(office layout/worker energy)
Methods	Within Subject Design
Participants	Subjects: 12 office employees (3 male, age: 36.5, 9 female, age 37.67) Inclusion: Healthy Exclusion: Unknown
Sit-stand Paradigm	2 Conditions: 1) Sit only work 2) Sit to stand work (stand 2 hours each day)
Outcome Measures	Employee satisfaction with work environment Tiredness
Notes	Conditions were not presented in random order Study was conducted in the field
Hasegawa 2001	
Methods	Within Subject Design, Random Presentation
Participants	Subjects: 18 male (age 19-25)
Sit-stand Paradigm	60 minute and 90 minute work sessions 6 different sit only, stand only or sit-stand paradigms for each
Outcome measures	Critical flicker fusion Subsidiary behaviours Subjective feelings of fatigue Performance
Notes	Study was conducted in a laboratory setting
Dainoff 2002	
Methods	Single intervention/No control
Participants	Subjects: 11 (age and gender unknown)
Sit-stand Paradigm	N/A

Outcome measures	Standing Frequency and Duration
Notes	Study protocol changed after first 3 subjects
Roelofs 2002	
Methods	Within Subject Design, Random Presentation Unknown
Participants	Subjects: 24 female, 6 male (age range: 18-52, mean age: 26.5)
Sit-stand Paradigm	3 Conditions: 1) Just sit 2) Just stand 3) Sit/Stand (alternate between sitting and standing every 30 minutes)
Outcome measures	Discomfort Subject preferred posture
Notes	Study was conducted in the field
Hedge 2004	
Methods	RCT Subjects: 54 intensive computer users (34 from a high tech company/20 from an insurance company, 31 males/23 females, age: 38.8 +/- 2.1) Inclusion Criteria: unknown Exclusion Criteria: unknown
Sit-stand Paradigm	2 Conditions: 1) Standard sitting workstation provided 2) Height Adjustable workstation provided
Outcome Measures	Frequency of Standing Work - Survey Musculoskeletal Discomfort - Survey (Zero to Ten scale)
Notes	Control group only had 10 participants Frequency of standing work was only measured using the survey Study was conducted in the field
Wilks 2005	
Methods	Survey
Participants	Subjects: 192 across four different companies

Sit-stand Paradigm	N/A
Outcome Measures	Various regarding attitude, compliance and satisfaction with sit-stand workstations
Notes	Nil
Hedge 2005	
Methods	Within Subject Design, Random Presentation
Participants	Subjects: 18 university students (12 women, 6 men, age: 19.7)
Sit-stand Paradigm	N/A
Outcome measures	Wrist posture Comfort Typing Performance Body Movements
Notes	Study was conducted in a laboratory setting
Ebara 2008	
Methods	Within Subject Design, Random Presentation
Participants	Subjects: 12 undergraduates (6 male/6 female, age: 21.2 +/- 1.1), 12 aged (6 male/6 female, 62.7 +/- 1.6) Inclusion Criteria: normal vision with or without glasses, experienced using a word processor and spreadsheet application, ability to type on a keyboard with both-hands, right-handed Exclusion Criteria: height less than 150 cm or greater than 180 cm, previous history of MSD within last year
Sit-stand Paradigm	3 Conditions: 1) Standard (sitting) - Three 40 minute blocks 2) High-chair (sitting) - Three 40 minute blocks 3) Sit-stand - Three 40 minute blocks (10 min sit, 5 min stand)
Outcome Measures	Discomfort - VAMS Work Performance Sleepiness - Sympathetic nerve activity (LF/HF ratio)
Notes	The sit-stand alternated between high chair and standing, not standard chair Study was conducted in a laboratory setting

Husemann 2009	
Methods	RCT
Participants	Subjects: 60 males from a university population (age: 18-35) Inclusion Criteria: not a professional with regard to data entry Exclusion: diseases, particularly problems with CNS
Sit-stand Paradigm	2 Conditions: 1) Sitting - Four 1 hour blocks (45 min sitting, 10 minute other, 5 minute break) 2) Sit-stand - Four 1 hour blocks (30 min sitting, 15 minute standing, 10 minute other, 5 minute break) *Repeated over 5 days
Outcome Measures	Discomfort - Giebener Beschwerdebogen Work Productivity - Key Strokes and Errors per minute
Notes	Study was conducted in a laboratory setting
Vink 2009	
Methods	Within Subject Design, Random Presentation
Participants	Subjects: 10 VDU workers (6 male/4 female, mean age: 38.1, mean height: 1.77m) Inclusion Criteria: VDU work for more than 6 hours per day, no diseases Exclusion Criteria: N/A
Sit-stand Paradigm	2 Conditions: 1) Two weeks using a standard workstation 2) Two weeks using a height adjustable workstation
Outcome Measures	Discomfort - Local postural discomfort questionnaire by Van Der Griten and Smitt[1992] Movement - 9-point scale
Notes	Sit-stand workstation had 3 different pre-set heights (sit, half sit, stand) Frequency of sit-stand work was only indirectly measured using movement survey Study was conducted in the field
Davis 2009	
Methods	Within Subject Design, Random Presentation
Participants	Subjects: 35 call center employees (27 female/8 male, age: unknown) Inclusion: Worked at the facility for at least one year

	Exclusion Criteria: N/A
Sit-stand Paradigm	4 Conditions: 1) conventional (sitting) 2) sit-stand 3) conventional with software reminder to change posture 4) sit-stand with reminder software *Each condition lasted 4 weeks
Outcome Measures	Discomfort - 10-point Likert scale Productivity - multiple measures Outcome measures were taken at the end of each day during the second two weel
Notes	Study was conducted in the field

APPENDIX B – Post-hoc Analysis of Discomfort

Post-hoc pairwise comparisons. All values reported are p-values. P < 0.05 comparisons are highlighted.

			Males											
			Sit											
			5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min	55 min	60 min
Males	Sit	5 min	1.000	0.820	0.403	0.316	0.267	0.273	0.539	0.233	0.322	0.405	0.573	0.571
		10 min	0.820	1.000	0.199	0.118	0.154	0.122	0.390	0.135	0.240	0.320	0.499	0.492
		15 min	0.403	0.199	1.000	0.904	0.651	0.758	0.964	0.575	0.624	0.723	0.873	0.886
		20 min	0.316	0.118	0.904	1.000	0.709	0.834	0.889	0.625	0.668	0.770	0.916	0.932
		25 min	0.267	0.154	0.651	0.709	1.000	0.852	0.672	0.912	0.894	0.981	0.913	0.891
		30 min	0.273	0.122	0.758	0.834	0.852	1.000	0.770	0.762	0.774	0.871	0.999	0.981
		35 min	0.539	0.390	0.964	0.889	0.672	0.770	1.000	0.603	0.635	0.724	0.861	0.873
		40 min	0.233	0.135	0.575	0.625	0.912	0.762	0.603	1.000	0.968	0.949	0.855	0.831
		45 min	0.322	0.240	0.624	0.668	0.894	0.774	0.635	0.968	1.000	0.928	0.844	0.822
		50 min	0.405	0.320	0.723	0.770	0.981	0.871	0.724	0.949	0.928	1.000	0.909	0.890
		55 min	0.573	0.499	0.873	0.916	0.913	0.999	0.861	0.855	0.844	0.909	1.000	0.985
		60 min	0.571	0.492	0.886	0.932	0.891	0.981	0.873	0.831	0.822	0.890	0.985	1.000
	Stand	5 min	0.810	0.969	0.210	0.131	0.158	0.130	0.392	0.139	0.241	0.320	0.497	0.490
		10 min	0.446	0.216	0.913	0.809	0.583	0.673	0.969	0.512	0.575	0.674	0.831	0.843
		15 min	0.235	0.088	0.714	0.790	0.877	0.965	0.737	0.783	0.792	0.890	0.983	0.962
		20 min	0.195	0.114	0.485	0.527	0.802	0.653	0.519	0.888	0.936	0.859	0.780	0.754
		25 min	0.107	0.064	0.267	0.288	0.491	0.372	0.302	0.560	0.636	0.582	0.545	0.517
		30 min	0.128	0.088	0.279	0.299	0.471	0.371	0.304	0.530	0.597	0.549	0.516	0.491
		35 min	0.104	0.065	0.253	0.273	0.462	0.351	0.286	0.527	0.602	0.551	0.519	0.491
		40 min	0.091	0.052	0.240	0.260	0.463	0.343	0.278	0.532	0.613	0.559	0.526	0.497
		45 min	0.056	0.036	0.131	0.141	0.252	0.184	0.153	0.293	0.360	0.329	0.323	0.300
		50 min	0.063	0.041	0.150	0.161	0.286	0.210	0.174	0.331	0.400	0.366	0.356	0.332
		55 min	0.052	0.030	0.134	0.144	0.274	0.194	0.160	0.321	0.397	0.363	0.354	0.329
		60 min	0.064	0.043	0.146	0.157	0.270	0.201	0.167	0.312	0.377	0.345	0.336	0.314
	Sit-Stand	5 min	0.878	0.572	0.401	0.293	0.264	0.258	0.570	0.230	0.334	0.424	0.603	0.601
		10 min	0.463	0.366	0.825	0.878	0.907	0.984	0.817	0.837	0.829	0.906	0.990	0.973
		15 min	0.406	0.250	0.907	0.984	0.757	0.877	0.890	0.678	0.702	0.795	0.929	0.944
		20 min	0.572	0.437	0.958	0.887	0.680	0.775	0.993	0.612	0.640	0.726	0.859	0.871
		25 min	0.472	0.398	0.766	0.808	0.993	0.896	0.761	0.945	0.925	0.991	0.923	0.906
		30 min	0.240	0.179	0.471	0.504	0.707	0.595	0.489	0.775	0.825	0.763	0.702	0.678
		35 min	0.186	0.135	0.380	0.407	0.596	0.489	0.402	0.661	0.719	0.663	0.616	0.591
		40 min	0.494	0.399	0.851	0.903	0.891	0.995	0.840	0.823	0.816	0.892	0.996	0.988
		45 min	0.310	0.229	0.610	0.653	0.882	0.760	0.622	0.956	0.990	0.917	0.834	0.812

		50 min	0.287	0.226	0.520	0.553	0.742	0.638	0.532	0.806	0.849	0.789	0.726	0.705
		55 min	0.171	0.120	0.363	0.390	0.587	0.475	0.389	0.653	0.715	0.658	0.611	0.586
		60 min	0.644	0.479	0.815	0.732	0.550	0.627	0.875	0.489	0.541	0.630	0.778	0.786
Females	Sit	5 min	0.847	0.974	0.234	0.152	0.171	0.147	0.413	0.150	0.252	0.332	0.509	0.502
		10 min	0.976	0.745	0.288	0.191	0.202	0.180	0.475	0.177	0.284	0.369	0.549	0.545
		15 min	0.643	0.354	0.638	0.524	0.402	0.438	0.757	0.350	0.440	0.537	0.708	0.713
		20 min	0.254	0.127	0.679	0.744	0.946	0.901	0.701	0.854	0.847	0.939	0.945	0.924
		25 min	0.306	0.206	0.659	0.711	0.970	0.836	0.672	0.948	0.925	0.994	0.896	0.874
		30 min	0.278	0.214	0.517	0.552	0.748	0.640	0.531	0.815	0.859	0.797	0.733	0.710
		35 min	0.237	0.198	0.394	0.416	0.550	0.474	0.404	0.598	0.642	0.598	0.560	0.541
		40 min	0.192	0.160	0.322	0.340	0.458	0.390	0.332	0.500	0.544	0.507	0.478	0.459
		45 min	0.314	0.280	0.457	0.478	0.585	0.525	0.460	0.624	0.655	0.618	0.581	0.565
		50 min	0.145	0.127	0.219	0.230	0.295	0.257	0.225	0.319	0.348	0.326	0.312	0.300
		55 min	0.158	0.140	0.232	0.243	0.307	0.270	0.237	0.330	0.357	0.336	0.320	0.309
		60 min	0.286	0.258	0.404	0.420	0.510	0.460	0.406	0.542	0.571	0.539	0.509	0.496
	Stand	5 min	0.955	0.716	0.381	0.284	0.253	0.249	0.539	0.220	0.319	0.405	0.581	0.578
		10 min	0.628	0.429	0.769	0.676	0.503	0.570	0.845	0.443	0.508	0.601	0.758	0.766
		15 min	0.759	0.609	0.720	0.642	0.488	0.551	0.790	0.434	0.489	0.574	0.723	0.728
		20 min	0.875	0.708	0.560	0.476	0.370	0.405	0.661	0.325	0.399	0.483	0.643	0.645
		25 min	0.760	0.616	0.730	0.654	0.499	0.563	0.797	0.444	0.496	0.580	0.727	0.733
		30 min	0.533	0.452	0.852	0.899	0.916	0.989	0.841	0.854	0.843	0.912	0.993	0.977
		35 min	0.473	0.385	0.809	0.858	0.939	0.957	0.802	0.872	0.859	0.932	0.970	0.953
		40 min	0.554	0.462	0.908	0.960	0.847	0.944	0.893	0.782	0.780	0.854	0.959	0.974
		45 min	0.396	0.330	0.657	0.695	0.876	0.779	0.659	0.938	0.968	0.906	0.832	0.813
		50 min	0.408	0.348	0.649	0.683	0.850	0.760	0.650	0.908	0.938	0.880	0.811	0.793
		55 min	0.419	0.366	0.635	0.665	0.814	0.733	0.634	0.866	0.896	0.843	0.782	0.764
		60 min	0.296	0.245	0.500	0.529	0.691	0.601	0.508	0.747	0.788	0.735	0.682	0.661
	Sit-Stand	5 min	0.319	0.149	0.049	0.022	0.056	0.031	0.172	0.051	0.126	0.182	0.336	0.322
		10 min	0.838	0.975	0.288	0.211	0.198	0.189	0.434	0.174	0.264	0.341	0.509	0.504
		15 min	0.949	0.774	0.466	0.380	0.306	0.325	0.587	0.268	0.352	0.435	0.600	0.599
		20 min	0.223	0.222	0.085	0.067	0.063	0.061	0.131	0.057	0.091	0.121	0.209	0.200
		25 min	0.169	0.119	0.036	0.022	0.036	0.024	0.099	0.033	0.078	0.113	0.225	0.212
		30 min	0.731	0.828	0.200	0.131	0.149	0.127	0.363	0.131	0.226	0.300	0.471	0.463
		35 min	0.864	0.708	0.593	0.513	0.395	0.438	0.684	0.349	0.417	0.500	0.656	0.658
		40 min	0.156	0.142	0.049	0.036	0.040	0.034	0.092	0.036	0.068	0.094	0.180	0.169
		45 min	0.422	0.357	0.088	0.050	0.079	0.056	0.218	0.071	0.149	0.208	0.363	0.351
		50 min	0.705	0.556	0.780	0.703	0.534	0.605	0.841	0.476	0.525	0.611	0.756	0.764
		55 min	0.449	0.354	0.802	0.854	0.930	0.960	0.797	0.860	0.849	0.925	0.973	0.956
		60 min	0.294	0.304	0.127	0.105	0.092	0.094	0.176	0.083	0.118	0.152	0.244	0.236
			Males											
			Stand											

			5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min	55 min	60 min
Males	Sit	5 min	0.810	0.446	0.235	0.195	0.107	0.128	0.104	0.091	0.056	0.063	0.052	0.064
		10 min	0.969	0.216	0.088	0.114	0.064	0.088	0.065	0.052	0.036	0.041	0.030	0.043
		15 min	0.210	0.913	0.714	0.485	0.267	0.279	0.253	0.240	0.131	0.150	0.134	0.146
		20 min	0.131	0.809	0.790	0.527	0.288	0.299	0.273	0.260	0.141	0.161	0.144	0.157
		25 min	0.158	0.583	0.877	0.802	0.491	0.471	0.462	0.463	0.252	0.286	0.274	0.270
		30 min	0.130	0.673	0.965	0.653	0.372	0.371	0.351	0.343	0.184	0.210	0.194	0.201
		35 min	0.392	0.969	0.737	0.519	0.302	0.304	0.286	0.278	0.153	0.174	0.160	0.167
		40 min	0.139	0.512	0.783	0.888	0.560	0.530	0.527	0.532	0.293	0.331	0.321	0.312
		45 min	0.241	0.575	0.792	0.936	0.636	0.597	0.602	0.613	0.360	0.400	0.397	0.377
		50 min	0.320	0.674	0.890	0.859	0.582	0.549	0.551	0.559	0.329	0.366	0.363	0.345
		55 min	0.497	0.831	0.983	0.780	0.545	0.516	0.519	0.526	0.323	0.356	0.354	0.336
		60 min	0.490	0.843	0.962	0.754	0.517	0.491	0.491	0.497	0.300	0.332	0.329	0.314
	Stand	5 min	1.000	0.229	0.097	0.117	0.065	0.089	0.066	0.053	0.037	0.041	0.031	0.044
		10 min	0.229	1.000	0.626	0.430	0.233	0.249	0.222	0.208	0.115	0.131	0.115	0.129
		15 min	0.097	0.626	1.000	0.670	0.379	0.378	0.357	0.349	0.186	0.213	0.196	0.204
		20 min	0.117	0.430	0.670	1.000	0.655	0.613	0.617	0.628	0.354	0.397	0.391	0.373
		25 min	0.065	0.233	0.379	0.655	1.000	0.922	0.951	0.979	0.608	0.669	0.679	0.627
		30 min	0.089	0.249	0.378	0.613	0.922	1.000	0.968	0.940	0.698	0.758	0.773	0.714
		35 min	0.066	0.222	0.357	0.617	0.951	0.968	1.000	0.971	0.654	0.715	0.728	0.671
		40 min	0.053	0.208	0.349	0.628	0.979	0.940	0.971	1.000	0.620	0.681	0.692	0.638
		45 min	0.037	0.115	0.186	0.354	0.608	0.698	0.654	0.620	1.000	0.933	0.905	0.988
		50 min	0.041	0.131	0.213	0.397	0.669	0.758	0.715	0.681	0.933	1.000	0.974	0.946
		55 min	0.031	0.115	0.196	0.391	0.679	0.773	0.728	0.692	0.905	0.974	1.000	0.919
		60 min	0.044	0.129	0.204	0.373	0.627	0.714	0.671	0.638	0.988	0.946	0.919	1.000
	Sit-Stand	5 min	0.583	0.447	0.211	0.191	0.103	0.129	0.101	0.087	0.054	0.062	0.049	0.063
		10 min	0.365	0.771	0.993	0.748	0.486	0.463	0.459	0.463	0.265	0.297	0.290	0.281
		15 min	0.255	0.831	0.842	0.583	0.336	0.337	0.318	0.310	0.168	0.191	0.177	0.184
		20 min	0.437	0.980	0.744	0.531	0.314	0.314	0.297	0.291	0.161	0.183	0.170	0.175
		25 min	0.396	0.723	0.914	0.863	0.607	0.571	0.577	0.586	0.359	0.396	0.395	0.374
		30 min	0.179	0.431	0.607	0.866	0.825	0.768	0.785	0.804	0.499	0.549	0.553	0.516
		35 min	0.136	0.344	0.499	0.749	0.940	0.873	0.897	0.921	0.588	0.643	0.652	0.604
		40 min	0.398	0.799	0.973	0.737	0.482	0.460	0.456	0.460	0.265	0.297	0.290	0.280
		45 min	0.230	0.560	0.778	0.947	0.644	0.604	0.609	0.620	0.363	0.404	0.401	0.381
		50 min	0.226	0.481	0.651	0.891	0.818	0.763	0.780	0.798	0.506	0.554	0.559	0.522
		55 min	0.121	0.327	0.485	0.744	0.936	0.867	0.891	0.915	0.577	0.632	0.641	0.594
		60 min	0.480	0.880	0.590	0.417	0.236	0.246	0.224	0.214	0.119	0.135	0.122	0.132
Females	Sit	5 min	0.950	0.257	0.112	0.126	0.070	0.094	0.070	0.057	0.039	0.044	0.033	0.046
		10 min	0.745	0.318	0.139	0.148	0.081	0.106	0.081	0.067	0.044	0.050	0.038	0.052
		15 min	0.370	0.710	0.387	0.291	0.156	0.179	0.150	0.135	0.079	0.090	0.075	0.090
		20 min	0.133	0.602	0.929	0.742	0.438	0.426	0.412	0.409	0.220	0.250	0.236	0.238

		25 min	0.208	0.600	0.858	0.845	0.540	0.512	0.509	0.514	0.288	0.323	0.315	0.305
		30 min	0.215	0.477	0.654	0.903	0.799	0.745	0.761	0.779	0.486	0.534	0.538	0.502
		35 min	0.197	0.368	0.483	0.663	0.906	0.970	0.943	0.920	0.776	0.829	0.845	0.788
		40 min	0.159	0.300	0.397	0.558	0.784	0.850	0.820	0.796	0.899	0.954	0.973	0.910
		45 min	0.279	0.436	0.533	0.676	0.874	0.927	0.904	0.885	0.856	0.902	0.918	0.866
		50 min	0.127	0.207	0.261	0.353	0.492	0.541	0.517	0.499	0.720	0.678	0.659	0.715
		55 min	0.139	0.220	0.274	0.363	0.497	0.544	0.521	0.504	0.716	0.675	0.657	0.710
		60 min	0.257	0.386	0.466	0.587	0.757	0.807	0.785	0.767	0.996	0.961	0.944	0.996
	Stand	5 min	0.713	0.424	0.207	0.184	0.100	0.124	0.098	0.084	0.053	0.060	0.048	0.061
		10 min	0.433	0.840	0.528	0.374	0.206	0.222	0.197	0.184	0.103	0.118	0.103	0.115
		15 min	0.606	0.778	0.517	0.370	0.210	0.221	0.200	0.190	0.107	0.121	0.109	0.118
		20 min	0.702	0.614	0.368	0.274	0.151	0.169	0.146	0.134	0.077	0.088	0.076	0.087
		25 min	0.612	0.788	0.529	0.380	0.217	0.227	0.207	0.197	0.110	0.125	0.113	0.122
		30 min	0.449	0.807	0.992	0.774	0.528	0.501	0.501	0.508	0.304	0.337	0.334	0.318
		35 min	0.384	0.760	0.977	0.786	0.525	0.498	0.498	0.503	0.295	0.328	0.324	0.310
		40 min	0.460	0.859	0.922	0.701	0.461	0.440	0.436	0.439	0.256	0.285	0.279	0.270
		45 min	0.328	0.617	0.794	0.980	0.713	0.668	0.679	0.693	0.436	0.478	0.481	0.451
		50 min	0.346	0.613	0.774	0.984	0.760	0.713	0.727	0.742	0.482	0.526	0.531	0.497
		55 min	0.364	0.602	0.746	0.935	0.826	0.777	0.793	0.809	0.550	0.594	0.602	0.563
		60 min	0.244	0.467	0.612	0.822	0.911	0.853	0.874	0.893	0.599	0.649	0.658	0.613
	Sit-Stand	5 min	0.223	0.049	0.019	0.045	0.028	0.045	0.029	0.022	0.018	0.020	0.014	0.022
		10 min	0.996	0.318	0.156	0.146	0.080	0.102	0.080	0.068	0.043	0.049	0.039	0.051
		15 min	0.766	0.514	0.287	0.225	0.123	0.143	0.120	0.107	0.064	0.072	0.060	0.073
		20 min	0.233	0.092	0.053	0.049	0.029	0.037	0.029	0.025	0.017	0.019	0.015	0.020
		25 min	0.140	0.038	0.017	0.029	0.018	0.029	0.019	0.014	0.012	0.013	0.009	0.015
		30 min	0.864	0.219	0.097	0.111	0.062	0.084	0.063	0.051	0.035	0.039	0.030	0.041
		35 min	0.702	0.647	0.402	0.295	0.164	0.180	0.158	0.146	0.084	0.095	0.083	0.094
		40 min	0.153	0.052	0.028	0.031	0.019	0.027	0.019	0.016	0.012	0.013	0.010	0.014
		45 min	0.412	0.093	0.039	0.061	0.036	0.054	0.038	0.029	0.022	0.025	0.018	0.027
		50 min	0.554	0.841	0.571	0.407	0.233	0.242	0.221	0.212	0.118	0.134	0.122	0.130
		55 min	0.353	0.750	0.982	0.770	0.504	0.480	0.477	0.481	0.277	0.310	0.303	0.293
		60 min	0.315	0.137	0.084	0.071	0.042	0.051	0.042	0.037	0.024	0.027	0.023	0.027

			Males											
			Sit-Stand											
			5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min	55 min	60 min
Males	Sit	5 min	0.878	0.463	0.406	0.572	0.472	0.240	0.186	0.494	0.310	0.287	0.171	0.644
		10 min	0.572	0.366	0.250	0.437	0.398	0.179	0.135	0.399	0.229	0.226	0.120	0.479
		15 min	0.401	0.825	0.907	0.958	0.766	0.471	0.380	0.851	0.610	0.520	0.363	0.815
		20 min	0.293	0.878	0.984	0.887	0.808	0.504	0.407	0.903	0.653	0.553	0.390	0.732
		25 min	0.264	0.907	0.757	0.680	0.993	0.707	0.596	0.891	0.882	0.742	0.587	0.550
		30 min	0.258	0.984	0.877	0.775	0.896	0.595	0.489	0.995	0.760	0.638	0.475	0.627

		35 min	0.570	0.817	0.890	0.993	0.761	0.489	0.402	0.840	0.622	0.532	0.389	0.875
		40 min	0.230	0.837	0.678	0.612	0.945	0.775	0.661	0.823	0.956	0.806	0.653	0.489
		45 min	0.334	0.829	0.702	0.640	0.925	0.825	0.719	0.816	0.990	0.849	0.715	0.541
		50 min	0.424	0.906	0.795	0.726	0.991	0.763	0.663	0.892	0.917	0.789	0.658	0.630
		55 min	0.603	0.990	0.929	0.859	0.923	0.702	0.616	0.996	0.834	0.726	0.611	0.778
		60 min	0.601	0.973	0.944	0.871	0.906	0.678	0.591	0.988	0.812	0.705	0.586	0.786
	Stand	5 min	0.583	0.365	0.255	0.437	0.396	0.179	0.136	0.398	0.230	0.226	0.121	0.480
		10 min	0.447	0.771	0.831	0.980	0.723	0.431	0.344	0.799	0.560	0.481	0.327	0.880
		15 min	0.211	0.993	0.842	0.744	0.914	0.607	0.499	0.973	0.778	0.651	0.485	0.590
		20 min	0.191	0.748	0.583	0.531	0.863	0.866	0.749	0.737	0.947	0.891	0.744	0.417
		25 min	0.103	0.486	0.336	0.314	0.607	0.825	0.940	0.482	0.644	0.818	0.936	0.236
		30 min	0.129	0.463	0.337	0.314	0.571	0.768	0.873	0.460	0.604	0.763	0.867	0.246
		35 min	0.101	0.459	0.318	0.297	0.577	0.785	0.897	0.456	0.609	0.780	0.891	0.224
		40 min	0.087	0.463	0.310	0.291	0.586	0.804	0.921	0.460	0.620	0.798	0.915	0.214
		45 min	0.054	0.265	0.168	0.161	0.359	0.499	0.588	0.265	0.363	0.506	0.577	0.119
		50 min	0.062	0.297	0.191	0.183	0.396	0.549	0.643	0.297	0.404	0.554	0.632	0.135
		55 min	0.049	0.290	0.177	0.170	0.395	0.553	0.652	0.290	0.401	0.559	0.641	0.122
		60 min	0.063	0.281	0.184	0.175	0.374	0.516	0.604	0.280	0.381	0.522	0.594	0.132
	Sit-Stand	5 min	1.000	0.487	0.416	0.607	0.496	0.247	0.190	0.520	0.321	0.298	0.173	0.690
		10 min	0.487	1.000	0.898	0.817	0.923	0.669	0.573	0.984	0.818	0.700	0.565	0.715
		15 min	0.416	0.898	1.000	0.888	0.827	0.540	0.444	0.920	0.688	0.583	0.431	0.756
		20 min	0.607	0.817	0.888	1.000	0.761	0.497	0.410	0.839	0.628	0.537	0.398	0.889
		25 min	0.496	0.923	0.827	0.761	1.000	0.772	0.679	0.909	0.915	0.795	0.675	0.676
		30 min	0.247	0.669	0.540	0.497	0.772	1.000	0.894	0.661	0.833	0.985	0.894	0.411
		35 min	0.190	0.573	0.444	0.410	0.679	0.894	1.000	0.567	0.727	0.883	0.997	0.333
		40 min	0.520	0.984	0.920	0.839	0.909	0.661	0.567	1.000	0.805	0.691	0.559	0.741
		45 min	0.321	0.818	0.688	0.628	0.915	0.833	0.727	0.805	1.000	0.857	0.723	0.528
		50 min	0.298	0.700	0.583	0.537	0.795	0.985	0.883	0.691	0.857	1.000	0.883	0.456
		55 min	0.173	0.565	0.431	0.398	0.675	0.894	0.997	0.559	0.723	0.883	1.000	0.318
		60 min	0.690	0.715	0.756	0.889	0.676	0.411	0.333	0.741	0.528	0.456	0.318	1.000
Females	Sit	5 min	0.638	0.379	0.275	0.457	0.407	0.187	0.142	0.412	0.241	0.234	0.127	0.505
		10 min	0.792	0.423	0.325	0.518	0.444	0.210	0.160	0.456	0.271	0.259	0.144	0.580
		15 min	0.687	0.617	0.605	0.783	0.599	0.327	0.256	0.648	0.426	0.378	0.238	0.898
		20 min	0.244	0.946	0.794	0.708	0.956	0.660	0.550	0.928	0.834	0.699	0.539	0.568
		25 min	0.313	0.888	0.750	0.678	0.985	0.744	0.636	0.873	0.913	0.774	0.628	0.563
		30 min	0.287	0.705	0.584	0.537	0.803	0.971	0.867	0.696	0.868	0.987	0.867	0.453
		35 min	0.246	0.529	0.438	0.408	0.611	0.780	0.866	0.524	0.647	0.774	0.861	0.352
		40 min	0.199	0.444	0.361	0.337	0.522	0.671	0.752	0.440	0.549	0.669	0.746	0.288
		45 min	0.326	0.561	0.492	0.462	0.625	0.769	0.841	0.555	0.660	0.764	0.837	0.416
		50 min	0.150	0.289	0.241	0.227	0.338	0.427	0.478	0.287	0.350	0.428	0.473	0.200
		55 min	0.163	0.299	0.253	0.239	0.346	0.433	0.483	0.297	0.359	0.434	0.478	0.212

		60 min	0.296	0.491	0.433	0.408	0.547	0.669	0.731	0.486	0.575	0.666	0.727	0.369
	Stand	5 min	0.912	0.465	0.395	0.576	0.476	0.237	0.182	0.497	0.307	0.286	0.166	0.651
		10 min	0.672	0.686	0.714	0.862	0.653	0.383	0.306	0.714	0.495	0.431	0.290	0.978
		15 min	0.819	0.651	0.674	0.807	0.623	0.372	0.301	0.677	0.477	0.416	0.287	0.905
		20 min	0.959	0.552	0.535	0.686	0.542	0.300	0.237	0.580	0.387	0.345	0.222	0.774
		25 min	0.820	0.658	0.683	0.813	0.629	0.379	0.307	0.683	0.484	0.422	0.293	0.911
		30 min	0.561	0.998	0.913	0.840	0.927	0.694	0.604	0.987	0.833	0.721	0.599	0.752
		35 min	0.497	0.976	0.877	0.802	0.946	0.702	0.607	0.961	0.849	0.730	0.601	0.706
		40 min	0.585	0.942	0.972	0.890	0.874	0.632	0.542	0.958	0.770	0.662	0.535	0.796
		45 min	0.414	0.820	0.718	0.661	0.904	0.875	0.780	0.809	0.977	0.894	0.778	0.580
		50 min	0.426	0.799	0.704	0.652	0.879	0.912	0.821	0.789	0.946	0.929	0.820	0.577
		55 min	0.437	0.769	0.683	0.636	0.844	0.965	0.879	0.760	0.903	0.979	0.879	0.570
		60 min	0.308	0.655	0.554	0.513	0.743	0.941	0.965	0.648	0.796	0.930	0.967	0.443
	Sit-Stand	5 min	0.103	0.202	0.089	0.213	0.252	0.097	0.072	0.230	0.119	0.132	0.061	0.208
		10 min	0.681	0.389	0.309	0.472	0.412	0.197	0.151	0.420	0.253	0.242	0.137	0.524
		15 min	0.947	0.497	0.457	0.617	0.499	0.263	0.206	0.527	0.340	0.309	0.190	0.696
		20 min	0.166	0.134	0.092	0.147	0.159	0.070	0.055	0.148	0.087	0.090	0.049	0.154
		25 min	0.080	0.123	0.055	0.123	0.165	0.061	0.045	0.142	0.073	0.085	0.038	0.118
		30 min	0.526	0.341	0.239	0.405	0.374	0.169	0.128	0.373	0.215	0.213	0.114	0.442
		35 min	0.942	0.570	0.563	0.707	0.556	0.314	0.250	0.597	0.405	0.359	0.236	0.796
		40 min	0.102	0.103	0.059	0.108	0.133	0.053	0.041	0.117	0.064	0.071	0.035	0.108
		45 min	0.221	0.233	0.127	0.258	0.278	0.113	0.085	0.261	0.141	0.150	0.073	0.264
		50 min	0.758	0.692	0.727	0.856	0.657	0.401	0.325	0.717	0.512	0.444	0.312	0.959
		55 min	0.471	0.980	0.876	0.797	0.940	0.687	0.590	0.964	0.838	0.717	0.583	0.696
		60 min	0.235	0.169	0.132	0.192	0.191	0.092	0.072	0.184	0.113	0.112	0.066	0.205
			Females											
			Sit											
			5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min	55 min	60 min
Males	Sit	5 min	0.847	0.976	0.643	0.254	0.306	0.278	0.237	0.192	0.314	0.145	0.158	0.286
		10 min	0.974	0.745	0.354	0.127	0.206	0.214	0.198	0.160	0.280	0.127	0.140	0.258
		15 min	0.234	0.288	0.638	0.679	0.659	0.517	0.394	0.322	0.457	0.219	0.232	0.404
		20 min	0.152	0.191	0.524	0.744	0.711	0.552	0.416	0.340	0.478	0.230	0.243	0.420
		25 min	0.171	0.202	0.402	0.946	0.970	0.748	0.550	0.458	0.585	0.295	0.307	0.510
		30 min	0.147	0.180	0.438	0.901	0.836	0.640	0.474	0.390	0.525	0.257	0.270	0.460
		35 min	0.413	0.475	0.757	0.701	0.672	0.531	0.404	0.332	0.460	0.225	0.237	0.406
		40 min	0.150	0.177	0.350	0.854	0.948	0.815	0.598	0.500	0.624	0.319	0.330	0.542
		45 min	0.252	0.284	0.440	0.847	0.925	0.859	0.642	0.544	0.655	0.348	0.357	0.571
		50 min	0.332	0.369	0.537	0.939	0.994	0.797	0.598	0.507	0.618	0.326	0.336	0.539
		55 min	0.509	0.549	0.708	0.945	0.896	0.733	0.560	0.478	0.581	0.312	0.320	0.509
		60 min	0.502	0.545	0.713	0.924	0.874	0.710	0.541	0.459	0.565	0.300	0.309	0.496
	Stand	5 min	0.950	0.745	0.370	0.133	0.208	0.215	0.197	0.159	0.279	0.127	0.139	0.257

		10 min	0.257	0.318	0.710	0.602	0.600	0.477	0.368	0.300	0.436	0.207	0.220	0.386
		15 min	0.112	0.139	0.387	0.929	0.858	0.654	0.483	0.397	0.533	0.261	0.274	0.466
		20 min	0.126	0.148	0.291	0.742	0.845	0.903	0.663	0.558	0.676	0.353	0.363	0.587
		25 min	0.070	0.081	0.156	0.438	0.540	0.799	0.906	0.784	0.874	0.492	0.497	0.757
		30 min	0.094	0.106	0.179	0.426	0.512	0.745	0.970	0.850	0.927	0.541	0.544	0.807
		35 min	0.070	0.081	0.150	0.412	0.509	0.761	0.943	0.820	0.904	0.517	0.521	0.785
		40 min	0.057	0.067	0.135	0.409	0.514	0.779	0.920	0.796	0.885	0.499	0.504	0.767
		45 min	0.039	0.044	0.079	0.220	0.288	0.486	0.776	0.899	0.856	0.720	0.716	0.996
		50 min	0.044	0.050	0.090	0.250	0.323	0.534	0.829	0.954	0.902	0.678	0.675	0.961
		55 min	0.033	0.038	0.075	0.236	0.315	0.538	0.845	0.973	0.918	0.659	0.657	0.944
		60 min	0.046	0.052	0.090	0.238	0.305	0.502	0.788	0.910	0.866	0.715	0.710	0.996
	Sit-Stand	5 min	0.638	0.792	0.687	0.244	0.313	0.287	0.246	0.199	0.326	0.150	0.163	0.296
		10 min	0.379	0.423	0.617	0.946	0.888	0.705	0.529	0.444	0.561	0.289	0.299	0.491
		15 min	0.275	0.325	0.605	0.794	0.750	0.584	0.438	0.361	0.492	0.241	0.253	0.433
		20 min	0.457	0.518	0.783	0.708	0.678	0.537	0.408	0.337	0.462	0.227	0.239	0.408
		25 min	0.407	0.444	0.599	0.956	0.985	0.803	0.611	0.522	0.625	0.338	0.346	0.547
		30 min	0.187	0.210	0.327	0.660	0.744	0.971	0.780	0.671	0.769	0.427	0.433	0.669
		35 min	0.142	0.160	0.256	0.550	0.636	0.867	0.866	0.752	0.841	0.478	0.483	0.731
		40 min	0.412	0.456	0.648	0.928	0.873	0.696	0.524	0.440	0.555	0.287	0.297	0.486
		45 min	0.241	0.271	0.426	0.834	0.913	0.868	0.647	0.549	0.660	0.350	0.359	0.575
		50 min	0.234	0.259	0.378	0.699	0.774	0.987	0.774	0.669	0.764	0.428	0.434	0.666
		55 min	0.127	0.144	0.238	0.539	0.628	0.867	0.861	0.746	0.837	0.473	0.478	0.727
		60 min	0.505	0.580	0.898	0.568	0.563	0.453	0.352	0.288	0.416	0.200	0.212	0.369
Females	Sit	5 min	1.000	0.806	0.412	0.147	0.221	0.223	0.203	0.164	0.284	0.130	0.142	0.261
		10 min	0.806	1.000	0.511	0.177	0.254	0.248	0.220	0.178	0.302	0.138	0.151	0.276
		15 min	0.412	0.511	1.000	0.397	0.439	0.371	0.300	0.243	0.376	0.175	0.189	0.336
		20 min	0.147	0.177	0.397	1.000	0.920	0.704	0.518	0.428	0.560	0.279	0.291	0.489
		25 min	0.221	0.254	0.439	0.920	1.000	0.782	0.578	0.484	0.606	0.311	0.322	0.528
		30 min	0.223	0.248	0.371	0.704	0.782	1.000	0.760	0.655	0.752	0.418	0.424	0.655
		35 min	0.203	0.220	0.300	0.518	0.578	0.760	1.000	0.894	0.957	0.593	0.593	0.844
		40 min	0.164	0.178	0.243	0.428	0.484	0.655	0.894	1.000	0.949	0.676	0.672	0.931
		45 min	0.284	0.302	0.376	0.560	0.606	0.752	0.957	0.949	1.000	0.659	0.656	0.893
		50 min	0.130	0.138	0.175	0.279	0.311	0.418	0.593	0.676	0.659	1.000	0.987	0.772
		55 min	0.142	0.151	0.189	0.291	0.322	0.424	0.593	0.672	0.656	0.987	1.000	0.766
		60 min	0.261	0.276	0.336	0.489	0.528	0.655	0.844	0.931	0.893	0.772	0.766	1.000
	Stand	5 min	0.760	0.910	0.639	0.235	0.299	0.276	0.238	0.192	0.317	0.146	0.159	0.288
		10 min	0.462	0.544	0.913	0.515	0.523	0.425	0.334	0.273	0.403	0.191	0.204	0.359
		15 min	0.631	0.711	0.982	0.501	0.504	0.412	0.324	0.265	0.389	0.186	0.199	0.347
		20 min	0.732	0.833	0.821	0.370	0.398	0.338	0.276	0.225	0.348	0.164	0.176	0.314
		25 min	0.637	0.715	0.987	0.512	0.513	0.418	0.328	0.269	0.392	0.188	0.200	0.350
		30 min	0.462	0.504	0.674	0.951	0.898	0.727	0.551	0.468	0.576	0.304	0.314	0.504

		35 min	0.397	0.438	0.617	0.977	0.919	0.736	0.554	0.468	0.580	0.304	0.313	0.508
		40 min	0.475	0.521	0.712	0.881	0.832	0.667	0.504	0.424	0.537	0.278	0.288	0.471
		45 min	0.338	0.370	0.506	0.838	0.903	0.905	0.692	0.596	0.694	0.384	0.391	0.606
		50 min	0.355	0.385	0.511	0.815	0.875	0.940	0.728	0.632	0.723	0.410	0.415	0.633
		55 min	0.372	0.400	0.512	0.782	0.837	0.989	0.780	0.685	0.767	0.450	0.454	0.674
		60 min	0.252	0.275	0.379	0.653	0.720	0.916	0.847	0.743	0.825	0.482	0.485	0.722
	Sit-Stand	5 min	0.227	0.117	0.072	0.039	0.092	0.122	0.130	0.105	0.207	0.093	0.104	0.196
		10 min	0.960	0.817	0.477	0.181	0.240	0.232	0.207	0.167	0.285	0.131	0.143	0.261
		15 min	0.800	0.915	0.718	0.299	0.341	0.301	0.252	0.205	0.327	0.152	0.165	0.296
		20 min	0.227	0.191	0.126	0.058	0.078	0.084	0.087	0.071	0.140	0.064	0.073	0.135
		25 min	0.138	0.095	0.056	0.027	0.056	0.077	0.089	0.073	0.153	0.069	0.078	0.149
		30 min	0.827	0.656	0.345	0.128	0.195	0.202	0.187	0.152	0.268	0.122	0.134	0.247
		35 min	0.730	0.824	0.849	0.399	0.420	0.353	0.285	0.233	0.355	0.168	0.180	0.319
		40 min	0.149	0.119	0.074	0.034	0.053	0.066	0.073	0.060	0.127	0.058	0.066	0.125
		45 min	0.400	0.273	0.145	0.061	0.117	0.140	0.142	0.115	0.219	0.099	0.110	0.206
		50 min	0.578	0.654	0.954	0.550	0.545	0.441	0.344	0.282	0.407	0.196	0.208	0.362
		55 min	0.367	0.409	0.598	0.970	0.910	0.723	0.542	0.456	0.572	0.296	0.306	0.500
		60 min	0.307	0.267	0.183	0.088	0.107	0.107	0.103	0.085	0.157	0.073	0.081	0.150

			Females											
			Stand											
			5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min	55 min	60 min
Males	Sit	5 min	0.955	0.628	0.759	0.875	0.760	0.533	0.473	0.554	0.396	0.408	0.419	0.296
		10 min	0.716	0.429	0.609	0.708	0.616	0.452	0.385	0.462	0.330	0.348	0.366	0.245
		15 min	0.381	0.769	0.720	0.560	0.730	0.852	0.809	0.908	0.657	0.649	0.635	0.500
		20 min	0.284	0.676	0.642	0.476	0.654	0.899	0.858	0.960	0.695	0.683	0.665	0.529
		25 min	0.253	0.503	0.488	0.370	0.499	0.916	0.939	0.847	0.876	0.850	0.814	0.691
		30 min	0.249	0.570	0.551	0.405	0.563	0.989	0.957	0.944	0.779	0.760	0.733	0.601
		35 min	0.539	0.845	0.790	0.661	0.797	0.841	0.802	0.893	0.659	0.650	0.634	0.508
		40 min	0.220	0.443	0.434	0.325	0.444	0.854	0.872	0.782	0.938	0.908	0.866	0.747
		45 min	0.319	0.508	0.489	0.399	0.496	0.843	0.859	0.780	0.968	0.938	0.896	0.788
		50 min	0.405	0.601	0.574	0.483	0.580	0.912	0.932	0.854	0.906	0.880	0.843	0.735
		55 min	0.581	0.758	0.723	0.643	0.727	0.993	0.970	0.959	0.832	0.811	0.782	0.682
		60 min	0.578	0.766	0.728	0.645	0.733	0.977	0.953	0.974	0.813	0.793	0.764	0.661
	Stand	5 min	0.713	0.433	0.606	0.702	0.612	0.449	0.384	0.460	0.328	0.346	0.364	0.244
		10 min	0.424	0.840	0.778	0.614	0.788	0.807	0.760	0.859	0.617	0.613	0.602	0.467
		15 min	0.207	0.528	0.517	0.368	0.529	0.992	0.977	0.922	0.794	0.774	0.746	0.612
		20 min	0.184	0.374	0.370	0.274	0.380	0.774	0.786	0.701	0.980	0.984	0.935	0.822
		25 min	0.100	0.206	0.210	0.151	0.217	0.528	0.525	0.461	0.713	0.760	0.826	0.911
		30 min	0.124	0.222	0.221	0.169	0.227	0.501	0.498	0.440	0.668	0.713	0.777	0.853
		35 min	0.098	0.197	0.200	0.146	0.207	0.501	0.498	0.436	0.679	0.727	0.793	0.874

		40 min	0.084	0.184	0.190	0.134	0.197	0.508	0.503	0.439	0.693	0.742	0.809	0.893
		45 min	0.053	0.103	0.107	0.077	0.110	0.304	0.295	0.256	0.436	0.482	0.550	0.599
		50 min	0.060	0.118	0.121	0.088	0.125	0.337	0.328	0.285	0.478	0.526	0.594	0.649
		55 min	0.048	0.103	0.109	0.076	0.113	0.334	0.324	0.279	0.481	0.531	0.602	0.658
		60 min	0.061	0.115	0.118	0.087	0.122	0.318	0.310	0.270	0.451	0.497	0.563	0.613
	Sit-Stand	5 min	0.912	0.672	0.819	0.959	0.820	0.561	0.497	0.585	0.414	0.426	0.437	0.308
		10 min	0.465	0.686	0.651	0.552	0.658	0.998	0.976	0.942	0.820	0.799	0.769	0.655
		15 min	0.395	0.714	0.674	0.535	0.683	0.913	0.877	0.972	0.718	0.704	0.683	0.554
		20 min	0.576	0.862	0.807	0.686	0.813	0.840	0.802	0.890	0.661	0.652	0.636	0.513
		25 min	0.476	0.653	0.623	0.542	0.629	0.927	0.946	0.874	0.904	0.879	0.844	0.743
		30 min	0.237	0.383	0.372	0.300	0.379	0.694	0.702	0.632	0.875	0.912	0.965	0.941
		35 min	0.182	0.306	0.301	0.237	0.307	0.604	0.607	0.542	0.780	0.821	0.879	0.965
		40 min	0.497	0.714	0.677	0.580	0.683	0.987	0.961	0.958	0.809	0.789	0.760	0.648
		45 min	0.307	0.495	0.477	0.387	0.484	0.833	0.849	0.770	0.977	0.946	0.903	0.796
		50 min	0.286	0.431	0.416	0.345	0.422	0.721	0.730	0.662	0.894	0.929	0.979	0.930
		55 min	0.166	0.290	0.287	0.222	0.293	0.599	0.601	0.535	0.778	0.820	0.879	0.967
		60 min	0.651	0.978	0.905	0.774	0.911	0.752	0.706	0.796	0.580	0.577	0.570	0.443
Females	Sit	5 min	0.760	0.462	0.631	0.732	0.637	0.462	0.397	0.475	0.338	0.355	0.372	0.252
		10 min	0.910	0.544	0.711	0.833	0.715	0.504	0.438	0.521	0.370	0.385	0.400	0.275
		15 min	0.639	0.913	0.982	0.821	0.987	0.674	0.617	0.712	0.506	0.511	0.512	0.379
		20 min	0.235	0.515	0.501	0.370	0.512	0.951	0.977	0.881	0.838	0.815	0.782	0.653
		25 min	0.299	0.523	0.504	0.398	0.513	0.898	0.919	0.832	0.903	0.875	0.837	0.720
		30 min	0.276	0.425	0.412	0.338	0.418	0.727	0.736	0.667	0.905	0.940	0.989	0.916
		35 min	0.238	0.334	0.324	0.276	0.328	0.551	0.554	0.504	0.692	0.728	0.780	0.847
		40 min	0.192	0.273	0.265	0.225	0.269	0.468	0.468	0.424	0.596	0.632	0.685	0.743
		45 min	0.317	0.403	0.389	0.348	0.392	0.576	0.580	0.537	0.694	0.723	0.767	0.825
		50 min	0.146	0.191	0.186	0.164	0.188	0.304	0.304	0.278	0.384	0.410	0.450	0.482
		55 min	0.159	0.204	0.199	0.176	0.200	0.314	0.313	0.288	0.391	0.415	0.454	0.485
		60 min	0.288	0.359	0.347	0.314	0.350	0.504	0.508	0.471	0.606	0.633	0.674	0.722
	Stand	5 min	1.000	0.631	0.775	0.901	0.776	0.539	0.476	0.561	0.398	0.411	0.423	0.297
		10 min	0.631	1.000	0.919	0.775	0.925	0.730	0.680	0.773	0.557	0.557	0.552	0.422
		15 min	0.775	0.919	1.000	0.879	0.996	0.694	0.647	0.732	0.534	0.534	0.530	0.407
		20 min	0.901	0.775	0.879	1.000	0.877	0.608	0.554	0.638	0.459	0.466	0.470	0.347
		25 min	0.776	0.925	0.996	0.877	1.000	0.699	0.653	0.738	0.539	0.539	0.534	0.412
		30 min	0.539	0.730	0.694	0.608	0.699	1.000	0.977	0.949	0.831	0.811	0.780	0.676
		35 min	0.476	0.680	0.647	0.554	0.653	0.977	1.000	0.922	0.846	0.824	0.792	0.683
		40 min	0.561	0.773	0.732	0.638	0.738	0.949	0.922	1.000	0.777	0.759	0.733	0.623
		45 min	0.398	0.557	0.534	0.459	0.539	0.831	0.846	0.777	1.000	0.971	0.929	0.834
		50 min	0.411	0.557	0.534	0.466	0.539	0.811	0.824	0.759	0.971	1.000	0.958	0.869

		55 min	0.423	0.552	0.530	0.470	0.534	0.780	0.792	0.733	0.929	0.958	1.000	0.918
		60 min	0.297	0.422	0.407	0.347	0.412	0.676	0.683	0.623	0.834	0.869	0.918	1.000
	Sit-Stand	5 min	0.192	0.152	0.299	0.320	0.312	0.287	0.226	0.281	0.208	0.230	0.256	0.156
		10 min	0.772	0.494	0.638	0.735	0.642	0.466	0.404	0.479	0.343	0.359	0.374	0.256
		15 min	0.985	0.688	0.807	0.925	0.807	0.562	0.504	0.587	0.420	0.430	0.438	0.315
		20 min	0.192	0.138	0.193	0.210	0.198	0.179	0.145	0.175	0.134	0.147	0.165	0.103
		25 min	0.115	0.088	0.169	0.174	0.177	0.186	0.142	0.177	0.136	0.156	0.179	0.104
		30 min	0.637	0.398	0.559	0.642	0.566	0.424	0.360	0.433	0.310	0.328	0.347	0.231
		35 min	0.888	0.800	0.897	0.984	0.895	0.623	0.571	0.654	0.473	0.478	0.480	0.358
		40 min	0.125	0.091	0.144	0.152	0.149	0.149	0.116	0.143	0.111	0.126	0.145	0.085
		45 min	0.313	0.214	0.359	0.397	0.370	0.315	0.256	0.313	0.230	0.251	0.274	0.172
		50 min	0.717	0.977	0.949	0.826	0.953	0.730	0.685	0.772	0.565	0.562	0.556	0.432
		55 min	0.450	0.667	0.634	0.536	0.640	0.980	0.995	0.923	0.837	0.815	0.784	0.671
		60 min	0.263	0.191	0.249	0.273	0.253	0.214	0.180	0.213	0.161	0.174	0.190	0.124

			Females											
			Sit-Stand											
			5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	50 min	55 min	60 min
Males	Sit	5 min	0.319	0.838	0.949	0.223	0.169	0.731	0.864	0.156	0.422	0.705	0.449	0.294
		10 min	0.149	0.975	0.774	0.222	0.119	0.828	0.708	0.142	0.357	0.556	0.354	0.304
		15 min	0.049	0.288	0.466	0.085	0.036	0.200	0.593	0.049	0.088	0.780	0.802	0.127
		20 min	0.022	0.211	0.380	0.067	0.022	0.131	0.513	0.036	0.050	0.703	0.854	0.105
		25 min	0.056	0.198	0.306	0.063	0.036	0.149	0.395	0.040	0.079	0.534	0.930	0.092
		30 min	0.031	0.189	0.325	0.061	0.024	0.127	0.438	0.034	0.056	0.605	0.960	0.094
		35 min	0.172	0.434	0.587	0.131	0.099	0.363	0.684	0.092	0.218	0.841	0.797	0.176
		40 min	0.051	0.174	0.268	0.057	0.033	0.131	0.349	0.036	0.071	0.476	0.860	0.083
		45 min	0.126	0.264	0.352	0.091	0.078	0.226	0.417	0.068	0.149	0.525	0.849	0.118
		50 min	0.182	0.341	0.435	0.121	0.113	0.300	0.500	0.094	0.208	0.611	0.925	0.152
		55 min	0.336	0.509	0.600	0.209	0.225	0.471	0.656	0.180	0.363	0.756	0.973	0.244
		60 min	0.322	0.504	0.599	0.200	0.212	0.463	0.658	0.169	0.351	0.764	0.956	0.236
	Stand	5 min	0.223	0.996	0.766	0.233	0.140	0.864	0.702	0.153	0.412	0.554	0.353	0.315
		10 min	0.049	0.318	0.514	0.092	0.038	0.219	0.647	0.052	0.093	0.841	0.750	0.137
		15 min	0.019	0.156	0.287	0.053	0.017	0.097	0.402	0.028	0.039	0.571	0.982	0.084
		20 min	0.045	0.146	0.225	0.049	0.029	0.111	0.295	0.031	0.061	0.407	0.770	0.071
		25 min	0.028	0.080	0.123	0.029	0.018	0.062	0.164	0.019	0.036	0.233	0.504	0.042
		30 min	0.045	0.102	0.143	0.037	0.029	0.084	0.180	0.027	0.054	0.242	0.480	0.051
		35 min	0.029	0.080	0.120	0.029	0.019	0.063	0.158	0.019	0.038	0.221	0.477	0.042
		40 min	0.022	0.068	0.107	0.025	0.014	0.051	0.146	0.016	0.029	0.212	0.481	0.037
		45 min	0.018	0.043	0.064	0.017	0.012	0.035	0.084	0.012	0.022	0.118	0.277	0.024
		50 min	0.020	0.049	0.072	0.019	0.013	0.039	0.095	0.013	0.025	0.134	0.310	0.027

		55 min	0.014	0.039	0.060	0.015	0.009	0.030	0.083	0.010	0.018	0.122	0.303	0.023
		60 min	0.022	0.051	0.073	0.020	0.015	0.041	0.094	0.014	0.027	0.130	0.293	0.027
	Sit-Stand	5 min	0.103	0.681	0.947	0.166	0.080	0.526	0.942	0.102	0.221	0.758	0.471	0.235
		10 min	0.202	0.389	0.497	0.134	0.123	0.341	0.570	0.103	0.233	0.692	0.980	0.169
		15 min	0.089	0.309	0.457	0.092	0.055	0.239	0.563	0.059	0.127	0.727	0.876	0.132
		20 min	0.213	0.472	0.617	0.147	0.123	0.405	0.707	0.108	0.258	0.856	0.797	0.192
		25 min	0.252	0.412	0.499	0.159	0.165	0.374	0.556	0.133	0.278	0.657	0.940	0.191
		30 min	0.097	0.197	0.263	0.070	0.061	0.169	0.314	0.053	0.113	0.401	0.687	0.092
		35 min	0.072	0.151	0.206	0.055	0.045	0.128	0.250	0.041	0.085	0.325	0.590	0.072
		40 min	0.230	0.420	0.527	0.148	0.142	0.373	0.597	0.117	0.261	0.717	0.964	0.184
		45 min	0.119	0.253	0.340	0.087	0.073	0.215	0.405	0.064	0.141	0.512	0.838	0.113
		50 min	0.132	0.242	0.309	0.090	0.085	0.213	0.359	0.071	0.150	0.444	0.717	0.112
		55 min	0.061	0.137	0.190	0.049	0.038	0.114	0.236	0.035	0.073	0.312	0.583	0.066
		60 min	0.208	0.524	0.696	0.154	0.118	0.442	0.796	0.108	0.264	0.959	0.696	0.205
Females	Sit	5 min	0.227	0.960	0.800	0.227	0.138	0.827	0.730	0.149	0.400	0.578	0.367	0.307
		10 min	0.117	0.817	0.915	0.191	0.095	0.656	0.824	0.119	0.273	0.654	0.409	0.267
		15 min	0.072	0.477	0.718	0.126	0.056	0.345	0.849	0.074	0.145	0.954	0.598	0.183
		20 min	0.039	0.181	0.299	0.058	0.027	0.128	0.399	0.034	0.061	0.550	0.970	0.088
		25 min	0.092	0.240	0.341	0.078	0.056	0.195	0.420	0.053	0.117	0.545	0.910	0.107
		30 min	0.122	0.232	0.301	0.084	0.077	0.202	0.353	0.066	0.140	0.441	0.723	0.107
		35 min	0.130	0.207	0.252	0.087	0.089	0.187	0.285	0.073	0.142	0.344	0.542	0.103
		40 min	0.105	0.167	0.205	0.071	0.073	0.152	0.233	0.060	0.115	0.282	0.456	0.085
		45 min	0.207	0.285	0.327	0.140	0.153	0.268	0.355	0.127	0.219	0.407	0.572	0.157
		50 min	0.093	0.131	0.152	0.064	0.069	0.122	0.168	0.058	0.099	0.196	0.296	0.073
		55 min	0.104	0.143	0.165	0.073	0.078	0.134	0.180	0.066	0.110	0.208	0.306	0.081
		60 min	0.196	0.261	0.296	0.135	0.149	0.247	0.319	0.125	0.206	0.362	0.500	0.150
	Stand	5 min	0.192	0.772	0.985	0.192	0.115	0.637	0.888	0.125	0.313	0.717	0.450	0.263
		10 min	0.152	0.494	0.688	0.138	0.088	0.398	0.800	0.091	0.214	0.977	0.667	0.191
		15 min	0.299	0.638	0.807	0.193	0.169	0.559	0.897	0.144	0.359	0.949	0.634	0.249
		20 min	0.320	0.735	0.925	0.210	0.174	0.642	0.984	0.152	0.397	0.826	0.536	0.273
		25 min	0.312	0.642	0.807	0.198	0.177	0.566	0.895	0.149	0.370	0.953	0.640	0.253
		30 min	0.287	0.466	0.562	0.179	0.186	0.424	0.623	0.149	0.315	0.730	0.980	0.214
		35 min	0.226	0.404	0.504	0.145	0.142	0.360	0.571	0.116	0.256	0.685	0.995	0.180
		40 min	0.281	0.479	0.587	0.175	0.177	0.433	0.654	0.143	0.313	0.772	0.923	0.213
		45 min	0.208	0.343	0.420	0.134	0.136	0.310	0.473	0.111	0.230	0.565	0.837	0.161
		50 min	0.230	0.359	0.430	0.147	0.156	0.328	0.478	0.126	0.251	0.562	0.815	0.174
		55 min	0.256	0.374	0.438	0.165	0.179	0.347	0.480	0.145	0.274	0.556	0.784	0.190
		60 min	0.156	0.256	0.315	0.103	0.104	0.231	0.358	0.085	0.172	0.432	0.671	0.124
	Sit-Stand	5 min	1.000	0.420	0.324	0.419	0.405	0.410	0.341	0.320	0.887	0.270	0.196	0.517

		10 min	0.420	1.000	0.796	0.264	0.214	0.901	0.731	0.190	0.540	0.589	0.377	0.342
		15 min	0.324	0.796	1.000	0.219	0.173	0.695	0.912	0.156	0.415	0.753	0.483	0.286
		20 min	0.419	0.264	0.219	1.000	0.761	0.274	0.216	0.970	0.405	0.179	0.130	0.948
		25 min	0.405	0.214	0.173	0.761	1.000	0.207	0.188	0.694	0.402	0.153	0.120	0.840
		30 min	0.410	0.901	0.695	0.274	0.207	1.000	0.645	0.192	0.568	0.512	0.331	0.358
		35 min	0.341	0.731	0.912	0.216	0.188	0.645	1.000	0.160	0.412	0.845	0.554	0.277
		40 min	0.320	0.190	0.156	0.970	0.694	0.192	0.160	1.000	0.313	0.132	0.101	0.916
		45 min	0.887	0.540	0.415	0.405	0.402	0.568	0.412	0.313	1.000	0.326	0.226	0.497
		50 min	0.270	0.589	0.753	0.179	0.153	0.512	0.845	0.132	0.326	1.000	0.674	0.232
		55 min	0.196	0.377	0.483	0.130	0.120	0.331	0.554	0.101	0.226	0.674	1.000	0.165
		60 min	0.517	0.342	0.286	0.948	0.840	0.358	0.277	0.916	0.497	0.232	0.165	1.000

APPENDIX C – Post-hoc Analysis of Material Testing

Post-hoc pairwise comparisons. All values reported are p-values. P < 0.05 comparisons are highlighted.

SINGLE LAYER – CIRCUMFERENTIAL DIRECTION (X-DIRECTION)

			Ant Sup											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	1.000	0.491	0.541	0.261	0.805	0.950	0.848	0.588	0.435	0.565	0.684	0.780
		E	0.491	1.000	0.850	0.668	0.284	0.443	0.531	0.193	0.155	0.187	0.243	0.273
	10	UE	0.541	0.850	1.000	0.428	0.293	0.481	0.591	0.195	0.160	0.190	0.251	0.280
		E	0.261	0.668	0.428	1.000	0.094	0.165	0.218	0.069	0.069	0.069	0.092	0.091
	15	UE	0.805	0.284	0.293	0.094	1.000	0.709	0.599	0.724	0.524	0.694	0.841	0.970
		E	0.950	0.443	0.481	0.165	0.709	1.000	0.873	0.486	0.355	0.465	0.586	0.683
	20	UE	0.848	0.531	0.591	0.218	0.599	0.873	1.000	0.405	0.300	0.389	0.496	0.576
		E	0.588	0.193	0.195	0.069	0.724	0.486	0.405	1.000	0.747	0.963	0.885	0.752
	25	UE	0.435	0.155	0.160	0.069	0.524	0.355	0.300	0.747	1.000	0.781	0.654	0.545
		E	0.565	0.187	0.190	0.069	0.694	0.465	0.389	0.963	0.781	1.000	0.851	0.721
	30	UE	0.684	0.243	0.251	0.092	0.841	0.586	0.496	0.885	0.654	0.851	1.000	0.870
		E	0.780	0.273	0.280	0.091	0.970	0.683	0.576	0.752	0.545	0.721	0.870	1.000
Ant Deep	5	UE	0.564	0.740	0.877	0.229	0.277	0.484	0.613	0.183	0.156	0.179	0.241	0.265
		E	0.940	0.571	0.633	0.341	0.751	0.978	0.927	0.554	0.412	0.533	0.642	0.729
	10	UE	0.078	0.020	0.018	0.007	0.089	0.051	0.041	0.164	0.309	0.180	0.133	0.095
		E	0.110	0.017	0.013	0.003	0.123	0.058	0.043	0.262	0.508	0.290	0.205	0.134
	15	UE	0.676	0.246	0.255	0.097	0.829	0.581	0.493	0.903	0.670	0.869	0.985	0.857
		E	0.630	0.240	0.252	0.106	0.766	0.542	0.463	0.980	0.743	0.946	0.913	0.792
	20	UE	0.121	0.019	0.014	0.004	0.137	0.065	0.048	0.286	0.543	0.316	0.225	0.149
		E	0.153	0.037	0.034	0.012	0.178	0.100	0.080	0.317	0.542	0.343	0.260	0.189
	25	UE	0.219	0.031	0.021	0.004	0.257	0.119	0.086	0.505	0.833	0.548	0.405	0.278
		E	0.172	0.042	0.038	0.014	0.201	0.115	0.091	0.354	0.590	0.382	0.291	0.214
	30	UE	0.152	0.022	0.016	0.003	0.173	0.080	0.058	0.361	0.654	0.396	0.284	0.188
		E	0.067	0.005	0.003	0.000	0.067	0.024	0.016	0.189	0.446	0.217	0.139	0.076
Post Sup	5	UE	0.070	0.190	0.048	0.200	0.012	0.020	0.027	0.012	0.019	0.013	0.016	0.012
		E	0.398	0.897	0.708	0.735	0.194	0.322	0.402	0.132	0.114	0.130	0.171	0.186
	10	UE	0.989	0.435	0.474	0.178	0.763	0.955	0.836	0.533	0.389	0.511	0.635	0.736
		E	0.427	0.949	0.766	0.669	0.213	0.354	0.439	0.145	0.123	0.142	0.187	0.204
	15	UE	0.220	0.605	0.317	0.947	0.061	0.110	0.152	0.049	0.055	0.050	0.066	0.060
		E	0.508	0.178	0.183	0.075	0.617	0.418	0.353	0.864	0.880	0.899	0.761	0.641
	20	UE	0.941	0.374	0.398	0.138	0.838	0.869	0.750	0.590	0.428	0.565	0.699	0.810
		E	0.755	0.319	0.341	0.152	0.914	0.677	0.589	0.839	0.628	0.808	0.944	0.940
	25	UE	0.249	0.059	0.054	0.017	0.297	0.169	0.134	0.503	0.780	0.538	0.418	0.315
		E	0.182	0.026	0.018	0.004	0.211	0.097	0.071	0.427	0.738	0.466	0.339	0.229

	30	UE	0.554	0.184	0.186	0.068	0.679	0.455	0.380	0.947	0.796	0.983	0.836	0.706
		E	0.035	0.006	0.004	0.001	0.037	0.017	0.013	0.086	0.205	0.098	0.066	0.040
Post Deep	5	UE	0.406	0.948	0.744	0.627	0.185	0.318	0.404	0.127	0.112	0.125	0.166	0.178
		E	0.100	0.276	0.084	0.339	0.019	0.032	0.045	0.018	0.026	0.019	0.025	0.019
	10	UE	0.428	0.980	0.785	0.596	0.202	0.344	0.434	0.137	0.120	0.135	0.179	0.194
		E	0.684	0.734	0.839	0.398	0.449	0.672	0.783	0.304	0.232	0.293	0.376	0.432
	15	UE	0.819	0.655	0.734	0.388	0.612	0.839	0.941	0.435	0.324	0.418	0.517	0.592
		E	0.239	0.073	0.072	0.030	0.283	0.177	0.146	0.450	0.686	0.479	0.381	0.298
	20	UE	0.146	0.042	0.040	0.017	0.171	0.103	0.085	0.288	0.481	0.311	0.240	0.181
		E	0.628	0.193	0.190	0.058	0.780	0.516	0.425	0.928	0.679	0.891	0.951	0.811
	25	UE	0.127	0.035	0.033	0.014	0.148	0.088	0.071	0.256	0.439	0.277	0.211	0.157
		E	0.232	0.048	0.041	0.011	0.275	0.148	0.115	0.489	0.779	0.526	0.401	0.294
	30	UE	0.115	0.027	0.024	0.009	0.132	0.073	0.058	0.244	0.440	0.266	0.197	0.141
		E	0.097	0.016	0.012	0.003	0.108	0.051	0.038	0.230	0.457	0.256	0.180	0.117
			Ant Deep											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.564	0.940	0.078	0.110	0.676	0.630	0.121	0.153	0.219	0.172	0.152	0.067
		E	0.740	0.571	0.020	0.017	0.246	0.240	0.019	0.037	0.031	0.042	0.022	0.005
	10	UE	0.877	0.633	0.018	0.013	0.255	0.252	0.014	0.034	0.021	0.038	0.016	0.003
		E	0.229	0.341	0.007	0.003	0.097	0.106	0.004	0.012	0.004	0.014	0.003	0.000
	15	UE	0.277	0.751	0.089	0.123	0.829	0.766	0.137	0.178	0.257	0.201	0.173	0.067
		E	0.484	0.978	0.051	0.058	0.581	0.542	0.065	0.100	0.119	0.115	0.080	0.024
	20	UE	0.613	0.927	0.041	0.043	0.493	0.463	0.048	0.080	0.086	0.091	0.058	0.016
		E	0.183	0.554	0.164	0.262	0.903	0.980	0.286	0.317	0.505	0.354	0.361	0.189
	25	UE	0.156	0.412	0.309	0.508	0.670	0.743	0.543	0.542	0.833	0.590	0.654	0.446
		E	0.179	0.533	0.180	0.290	0.869	0.946	0.316	0.343	0.548	0.382	0.396	0.217
	30	UE	0.241	0.642	0.133	0.205	0.985	0.913	0.225	0.260	0.405	0.291	0.284	0.139
		E	0.265	0.729	0.095	0.134	0.857	0.792	0.149	0.189	0.278	0.214	0.188	0.076
Ant Deep	5	UE	1.000	0.666	0.016	0.009	0.248	0.249	0.010	0.029	0.012	0.034	0.010	0.001
		E	0.666	1.000	0.077	0.110	0.635	0.593	0.121	0.149	0.215	0.167	0.151	0.071
	10	UE	0.016	0.077	1.000	0.604	0.141	0.176	0.567	0.640	0.315	0.586	0.449	0.600
		E	0.009	0.110	0.604	1.000	0.219	0.282	0.947	0.990	0.547	0.940	0.775	0.964
	15	UE	0.248	0.635	0.141	0.219	1.000	0.929	0.240	0.273	0.428	0.305	0.303	0.153
		E	0.249	0.593	0.176	0.282	0.929	1.000	0.307	0.331	0.522	0.367	0.382	0.216
	20	UE	0.010	0.121	0.567	0.947	0.240	0.307	1.000	0.944	0.594	0.986	0.828	0.904
		E	0.029	0.149	0.640	0.990	0.273	0.331	0.944	1.000	0.597	0.937	0.794	0.980
	25	UE	0.012	0.215	0.315	0.547	0.428	0.522	0.594	0.597	1.000	0.659	0.744	0.449
		E	0.034	0.167	0.586	0.940	0.305	0.367	0.986	0.937	0.659	1.000	0.863	0.903
	30	UE	0.010	0.151	0.449	0.775	0.303	0.382	0.828	0.794	0.744	0.863	1.000	0.706
		E	0.001	0.071	0.600	0.964	0.153	0.216	0.904	0.980	0.449	0.903	0.706	1.000
Post Sup	5	UE	0.003	0.113	0.002	0.000	0.019	0.025	0.000	0.003	0.000	0.003	0.000	0.000
		E	0.554	0.482	0.013	0.009	0.176	0.178	0.010	0.023	0.014	0.027	0.010	0.002
	10	UE	0.481	0.944	0.059	0.074	0.628	0.585	0.082	0.118	0.152	0.134	0.102	0.035

		E	0.616	0.513	0.014	0.010	0.192	0.193	0.011	0.025	0.015	0.029	0.011	0.002
	15	UE	0.074	0.301	0.006	0.002	0.072	0.084	0.002	0.009	0.001	0.010	0.002	0.000
		E	0.177	0.480	0.235	0.387	0.778	0.853	0.417	0.431	0.680	0.475	0.513	0.318
	20	UE	0.393	0.878	0.067	0.085	0.690	0.640	0.095	0.133	0.177	0.151	0.119	0.041
		E	0.345	0.710	0.136	0.211	0.930	0.867	0.231	0.260	0.402	0.289	0.289	0.152
	25	UE	0.046	0.240	0.406	0.681	0.436	0.513	0.726	0.706	0.908	0.766	0.871	0.616
		E	0.011	0.180	0.381	0.662	0.360	0.446	0.713	0.697	0.864	0.763	0.876	0.578
	30	UE	0.176	0.522	0.187	0.303	0.853	0.930	0.330	0.355	0.568	0.395	0.413	0.230
		E	0.003	0.036	0.884	0.451	0.071	0.098	0.414	0.502	0.185	0.449	0.301	0.430
Post Deep	5	UE	0.557	0.497	0.012	0.007	0.172	0.177	0.008	0.021	0.010	0.024	0.008	0.001
		E	0.006	0.153	0.003	0.001	0.028	0.036	0.001	0.004	0.000	0.004	0.000	0.000
	10	UE	0.610	0.518	0.013	0.008	0.185	0.188	0.009	0.023	0.012	0.027	0.009	0.001
		E	0.907	0.765	0.031	0.031	0.376	0.359	0.035	0.060	0.060	0.068	0.041	0.011
	15	UE	0.779	0.888	0.053	0.068	0.512	0.481	0.075	0.103	0.135	0.116	0.093	0.037
		E	0.067	0.229	0.534	0.848	0.396	0.459	0.891	0.853	0.778	0.912	0.971	0.807
	20	UE	0.037	0.142	0.758	0.869	0.251	0.300	0.827	0.888	0.523	0.829	0.693	0.886
		E	0.172	0.589	0.133	0.204	0.968	0.954	0.225	0.264	0.413	0.296	0.286	0.132
	25	UE	0.031	0.124	0.807	0.810	0.221	0.268	0.768	0.833	0.472	0.775	0.636	0.822
		E	0.032	0.224	0.388	0.660	0.421	0.502	0.706	0.689	0.912	0.751	0.855	0.587
	30	UE	0.021	0.113	0.767	0.835	0.209	0.258	0.790	0.859	0.469	0.797	0.647	0.850
		E	0.009	0.097	0.671	0.914	0.193	0.250	0.862	0.933	0.482	0.864	0.695	0.937

			Post Sup											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.070	0.398	0.989	0.427	0.220	0.508	0.941	0.755	0.249	0.182	0.554	0.035
		E	0.190	0.897	0.435	0.949	0.605	0.178	0.374	0.319	0.059	0.026	0.184	0.006
	10	UE	0.048	0.708	0.474	0.766	0.317	0.183	0.398	0.341	0.054	0.018	0.186	0.004
		E	0.200	0.735	0.178	0.669	0.947	0.075	0.138	0.152	0.017	0.004	0.068	0.001
	15	UE	0.012	0.194	0.763	0.213	0.061	0.617	0.838	0.914	0.297	0.211	0.679	0.037
		E	0.020	0.322	0.955	0.354	0.110	0.418	0.869	0.677	0.169	0.097	0.455	0.017
	20	UE	0.027	0.402	0.836	0.439	0.152	0.353	0.750	0.589	0.134	0.071	0.380	0.013
		E	0.012	0.132	0.533	0.145	0.049	0.864	0.590	0.839	0.503	0.427	0.947	0.086
	25	UE	0.019	0.114	0.389	0.123	0.055	0.880	0.428	0.628	0.780	0.738	0.796	0.205
		E	0.013	0.130	0.511	0.142	0.050	0.899	0.565	0.808	0.538	0.466	0.983	0.098
	30	UE	0.016	0.171	0.635	0.187	0.066	0.761	0.699	0.944	0.418	0.339	0.836	0.066
		E	0.012	0.186	0.736	0.204	0.060	0.641	0.810	0.940	0.315	0.229	0.706	0.040
Ant Deep	5	UE	0.003	0.554	0.481	0.616	0.074	0.177	0.393	0.345	0.046	0.011	0.176	0.003
		E	0.113	0.482	0.944	0.513	0.301	0.480	0.878	0.710	0.240	0.180	0.522	0.036
	10	UE	0.002	0.013	0.059	0.014	0.006	0.235	0.067	0.136	0.406	0.381	0.187	0.884
		E	0.000	0.009	0.074	0.010	0.002	0.387	0.085	0.211	0.681	0.662	0.303	0.451
	15	UE	0.019	0.176	0.628	0.192	0.072	0.778	0.690	0.930	0.436	0.360	0.853	0.071
		E	0.025	0.178	0.585	0.193	0.084	0.853	0.640	0.867	0.513	0.446	0.930	0.098
	20	UE	0.000	0.010	0.082	0.011	0.002	0.417	0.095	0.231	0.726	0.713	0.330	0.414
		E	0.003	0.023	0.118	0.025	0.009	0.431	0.133	0.260	0.706	0.697	0.355	0.502

	25	UE	0.000	0.014	0.152	0.015	0.001	0.680	0.177	0.402	0.908	0.864	0.568	0.185
		E	0.003	0.027	0.134	0.029	0.010	0.475	0.151	0.289	0.766	0.763	0.395	0.449
	30	UE	0.000	0.010	0.102	0.011	0.002	0.513	0.119	0.289	0.871	0.876	0.413	0.301
		E	0.000	0.002	0.035	0.002	0.000	0.318	0.041	0.152	0.616	0.578	0.230	0.430
Post Sup	5	UE	1.000	0.161	0.027	0.132	0.095	0.018	0.018	0.039	0.003	0.000	0.013	0.000
		E	0.161	1.000	0.324	0.939	0.657	0.129	0.267	0.245	0.036	0.012	0.127	0.003
	10	UE	0.027	0.324	1.000	0.354	0.128	0.458	0.919	0.720	0.198	0.125	0.500	0.022
		E	0.132	0.939	0.354	1.000	0.583	0.140	0.293	0.265	0.040	0.013	0.139	0.003
	15	UE	0.095	0.657	0.128	0.583	1.000	0.058	0.093	0.124	0.011	0.002	0.050	0.001
		E	0.018	0.129	0.458	0.140	0.058	1.000	0.505	0.726	0.648	0.591	0.915	0.142
	20	UE	0.018	0.267	0.919	0.293	0.093	0.505	1.000	0.781	0.224	0.145	0.553	0.025
		E	0.039	0.245	0.720	0.265	0.124	0.726	0.781	1.000	0.410	0.341	0.793	0.071
	25	UE	0.003	0.036	0.198	0.040	0.011	0.648	0.224	0.410	1.000	0.977	0.554	0.277
		E	0.000	0.012	0.125	0.013	0.002	0.591	0.145	0.341	0.977	1.000	0.484	0.240
	30	UE	0.013	0.127	0.500	0.139	0.050	0.915	0.553	0.793	0.554	0.484	1.000	0.103
		E	0.000	0.003	0.022	0.003	0.001	0.142	0.025	0.071	0.277	0.240	0.103	1.000
Post Deep	5	UE	0.080	0.931	0.323	0.997	0.511	0.126	0.262	0.246	0.033	0.009	0.123	0.003
		E	0.615	0.254	0.043	0.212	0.199	0.025	0.029	0.055	0.004	0.000	0.019	0.000
	10	UE	0.078	0.895	0.347	0.960	0.482	0.135	0.283	0.261	0.036	0.010	0.133	0.003
		E	0.081	0.612	0.649	0.658	0.327	0.271	0.573	0.463	0.099	0.050	0.287	0.010
	15	UE	0.115	0.554	0.809	0.591	0.339	0.379	0.738	0.593	0.168	0.112	0.410	0.021
		E	0.008	0.051	0.200	0.055	0.023	0.571	0.223	0.373	0.869	0.877	0.492	0.407
	20	UE	0.005	0.029	0.118	0.031	0.013	0.385	0.132	0.239	0.621	0.608	0.321	0.631
		E	0.008	0.125	0.569	0.138	0.037	0.793	0.632	0.897	0.430	0.343	0.874	0.063
	25	UE	0.004	0.024	0.101	0.026	0.011	0.348	0.113	0.211	0.570	0.554	0.286	0.680
		E	0.002	0.027	0.177	0.030	0.007	0.642	0.202	0.396	0.992	0.967	0.543	0.256
	30	UE	0.002	0.017	0.087	0.019	0.006	0.342	0.098	0.200	0.578	0.558	0.276	0.631
		E	0.000	0.008	0.065	0.009	0.002	0.344	0.075	0.186	0.614	0.589	0.267	0.519
			Post Deep											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.406	0.100	0.428	0.684	0.819	0.239	0.146	0.628	0.127	0.232	0.115	0.097
		E	0.948	0.276	0.980	0.734	0.655	0.073	0.042	0.193	0.035	0.048	0.027	0.016
	10	UE	0.744	0.084	0.785	0.839	0.734	0.072	0.040	0.190	0.033	0.041	0.024	0.012
		E	0.627	0.339	0.596	0.398	0.388	0.030	0.017	0.058	0.014	0.011	0.009	0.003
	15	UE	0.185	0.019	0.202	0.449	0.612	0.283	0.171	0.780	0.148	0.275	0.132	0.108
		E	0.318	0.032	0.344	0.672	0.839	0.177	0.103	0.516	0.088	0.148	0.073	0.051
	20	UE	0.404	0.045	0.434	0.783	0.941	0.146	0.085	0.425	0.071	0.115	0.058	0.038
		E	0.127	0.018	0.137	0.304	0.435	0.450	0.288	0.928	0.256	0.489	0.244	0.230
	25	UE	0.112	0.026	0.120	0.232	0.324	0.686	0.481	0.679	0.439	0.779	0.440	0.457
		E	0.125	0.019	0.135	0.293	0.418	0.479	0.311	0.891	0.277	0.526	0.266	0.256
	30	UE	0.166	0.025	0.179	0.376	0.517	0.381	0.240	0.951	0.211	0.401	0.197	0.180
		E	0.178	0.019	0.194	0.432	0.592	0.298	0.181	0.811	0.157	0.294	0.141	0.117
Ant Deep	5	UE	0.557	0.006	0.610	0.907	0.779	0.067	0.037	0.172	0.031	0.032	0.021	0.009

		E	0.497	0.153	0.518	0.765	0.888	0.229	0.142	0.589	0.124	0.224	0.113	0.097
	10	UE	0.012	0.003	0.013	0.031	0.053	0.534	0.758	0.133	0.807	0.388	0.767	0.671
		E	0.007	0.001	0.008	0.031	0.068	0.848	0.869	0.204	0.810	0.660	0.835	0.914
	15	UE	0.172	0.028	0.185	0.376	0.512	0.396	0.251	0.968	0.221	0.421	0.209	0.193
		E	0.177	0.036	0.188	0.359	0.481	0.459	0.300	0.954	0.268	0.502	0.258	0.250
	20	UE	0.008	0.001	0.009	0.035	0.075	0.891	0.827	0.225	0.768	0.706	0.790	0.862
		E	0.021	0.004	0.023	0.060	0.103	0.853	0.888	0.264	0.833	0.689	0.859	0.933
	25	UE	0.010	0.000	0.012	0.060	0.135	0.778	0.523	0.413	0.472	0.912	0.469	0.482
		E	0.024	0.004	0.027	0.068	0.116	0.912	0.829	0.296	0.775	0.751	0.797	0.864
	30	UE	0.008	0.000	0.009	0.041	0.093	0.971	0.693	0.286	0.636	0.855	0.647	0.695
		E	0.001	0.000	0.001	0.011	0.037	0.807	0.886	0.132	0.822	0.587	0.850	0.937
Post Sup	5	UE	0.080	0.615	0.078	0.081	0.115	0.008	0.005	0.008	0.004	0.002	0.002	0.000
		E	0.931	0.254	0.895	0.612	0.554	0.051	0.029	0.125	0.024	0.027	0.017	0.008
	10	UE	0.323	0.043	0.347	0.649	0.809	0.200	0.118	0.569	0.101	0.177	0.087	0.065
		E	0.997	0.212	0.960	0.658	0.591	0.055	0.031	0.138	0.026	0.030	0.019	0.009
	15	UE	0.511	0.199	0.482	0.327	0.339	0.023	0.013	0.037	0.011	0.007	0.006	0.002
		E	0.126	0.025	0.135	0.271	0.379	0.571	0.385	0.793	0.348	0.642	0.342	0.344
	20	UE	0.262	0.029	0.283	0.573	0.738	0.223	0.132	0.632	0.113	0.202	0.098	0.075
		E	0.246	0.055	0.261	0.463	0.593	0.373	0.239	0.897	0.211	0.396	0.200	0.186
	25	UE	0.033	0.004	0.036	0.099	0.168	0.869	0.621	0.430	0.570	0.992	0.578	0.614
		E	0.009	0.000	0.010	0.050	0.112	0.877	0.608	0.343	0.554	0.967	0.558	0.589
	30	UE	0.123	0.019	0.133	0.287	0.410	0.492	0.321	0.874	0.286	0.543	0.276	0.267
		E	0.003	0.000	0.003	0.010	0.021	0.407	0.631	0.063	0.680	0.256	0.631	0.519
Post Deep	5	UE	1.000	0.142	0.959	0.636	0.574	0.049	0.028	0.117	0.023	0.023	0.016	0.007
		E	0.142	1.000	0.136	0.124	0.161	0.011	0.006	0.012	0.005	0.002	0.003	0.001
	10	UE	0.959	0.136	1.000	0.669	0.599	0.053	0.030	0.128	0.024	0.026	0.017	0.007
		E	0.636	0.124	0.669	1.000	0.877	0.112	0.065	0.314	0.055	0.083	0.044	0.028
	15	UE	0.574	0.161	0.599	0.877	1.000	0.170	0.102	0.460	0.088	0.152	0.076	0.060
		E	0.049	0.011	0.053	0.112	0.170	1.000	0.757	0.392	0.707	0.858	0.724	0.779
	20	UE	0.028	0.006	0.030	0.065	0.102	0.757	1.000	0.244	0.948	0.605	0.979	0.941
		E	0.117	0.012	0.128	0.314	0.460	0.392	0.244	1.000	0.214	0.412	0.199	0.178
	25	UE	0.023	0.005	0.024	0.055	0.088	0.707	0.948	0.214	1.000	0.553	0.967	0.882
		E	0.023	0.002	0.026	0.083	0.152	0.858	0.605	0.412	0.553	1.000	0.558	0.591
	30	UE	0.016	0.003	0.017	0.044	0.076	0.724	0.979	0.199	0.967	0.558	1.000	0.912
		E	0.007	0.001	0.007	0.028	0.060	0.779	0.941	0.178	0.882	0.591	0.912	1.000

SINGLE LAYER – LONGITUDINAL DIRECTION (Y-DIRECTION)

			Ant Sup											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	1.000	0.257	0.795	0.667	0.998	0.984	0.024	0.622	0.088	0.197	0.992	0.323
		E	0.257	1.000	0.189	0.333	0.469	0.157	0.087	0.286	0.416	0.064	0.395	0.778
	10	UE	0.795	0.189	1.000	0.491	0.846	0.785	0.022	0.742	0.069	0.263	0.820	0.235
		E	0.667	0.333	0.491	1.000	0.785	0.580	0.008	0.467	0.071	0.122	0.752	0.443
	15	UE	0.998	0.469	0.846	0.785	1.000	0.987	0.162	0.664	0.285	0.254	0.996	0.538
		E	0.984	0.157	0.785	0.580	0.987	1.000	0.004	0.615	0.032	0.184	0.979	0.207
	20	UE	0.024	0.087	0.022	0.008	0.162	0.004	1.000	0.118	0.314	0.021	0.096	0.027
		E	0.622	0.286	0.742	0.467	0.664	0.615	0.118	1.000	0.186	0.519	0.642	0.324
	25	UE	0.088	0.416	0.069	0.071	0.285	0.032	0.314	0.186	1.000	0.036	0.205	0.232
		E	0.197	0.064	0.263	0.122	0.254	0.184	0.021	0.519	0.036	1.000	0.225	0.074
	30	UE	0.992	0.395	0.820	0.752	0.996	0.979	0.096	0.642	0.205	0.225	1.000	0.467
		E	0.323	0.778	0.235	0.443	0.538	0.207	0.027	0.324	0.232	0.074	0.467	1.000
Ant Deep	5	UE	0.956	0.225	0.832	0.616	0.967	0.966	0.019	0.642	0.073	0.205	0.956	0.285
		E	0.240	0.914	0.177	0.310	0.444	0.150	0.147	0.273	0.523	0.061	0.371	0.707
	10	UE	0.047	0.206	0.039	0.022	0.221	0.011	0.477	0.151	0.659	0.028	0.145	0.081
		E	0.750	0.197	0.944	0.473	0.807	0.738	0.030	0.782	0.081	0.292	0.779	0.242
	15	UE	0.430	0.886	0.325	0.595	0.570	0.363	0.228	0.349	0.501	0.091	0.521	0.971
		E	0.098	0.042	0.124	0.068	0.121	0.093	0.019	0.244	0.028	0.510	0.109	0.047
	20	UE	0.167	0.820	0.126	0.167	0.403	0.070	0.034	0.250	0.418	0.052	0.319	0.538
		E	0.403	0.113	0.534	0.244	0.488	0.382	0.027	0.872	0.056	0.573	0.448	0.134
	25	UE	0.328	0.168	0.392	0.251	0.363	0.322	0.086	0.590	0.120	0.992	0.344	0.185
		E	0.034	0.008	0.051	0.017	0.059	0.029	0.002	0.182	0.004	0.483	0.046	0.009
	30	UE	0.490	0.201	0.603	0.349	0.546	0.479	0.075	0.883	0.124	0.612	0.517	0.230
		E	0.148	0.044	0.204	0.088	0.202	0.137	0.014	0.444	0.025	0.906	0.175	0.051
Post Sup	5	UE	0.984	0.270	0.781	0.686	0.991	0.967	0.027	0.614	0.095	0.194	0.995	0.339
		E	0.167	0.754	0.125	0.181	0.387	0.080	0.114	0.241	0.577	0.051	0.306	0.515
	10	UE	0.021	0.072	0.020	0.006	0.153	0.003	0.913	0.113	0.267	0.020	0.089	0.021
		E	0.230	0.895	0.170	0.293	0.436	0.140	0.145	0.269	0.531	0.059	0.362	0.684
	15	UE	0.250	0.076	0.335	0.152	0.319	0.234	0.022	0.630	0.041	0.846	0.285	0.089
		E	0.813	0.238	0.608	0.804	0.880	0.754	0.005	0.526	0.048	0.146	0.865	0.316
	20	UE	0.962	0.380	0.783	0.765	0.973	0.945	0.078	0.618	0.183	0.207	0.975	0.456
		E	0.047	0.010	0.072	0.023	0.082	0.040	0.002	0.243	0.005	0.614	0.064	0.012
	25	UE	0.145	0.599	0.109	0.164	0.337	0.077	0.343	0.214	0.865	0.045	0.262	0.417
		E	0.016	0.006	0.022	0.010	0.023	0.015	0.002	0.062	0.004	0.166	0.019	0.006
	30	UE	0.919	0.461	0.755	0.835	0.939	0.900	0.124	0.602	0.251	0.207	0.936	0.540
		E	0.112	0.022	0.169	0.054	0.178	0.097	0.005	0.450	0.010	0.966	0.146	0.026
Post Deep	5	UE	0.185	0.018	0.304	0.066	0.313	0.150	0.001	0.726	0.005	0.649	0.255	0.022
		E	0.898	0.367	0.939	0.667	0.916	0.902	0.107	0.723	0.205	0.280	0.904	0.428
	10	UE	0.253	0.065	0.350	0.144	0.335	0.234	0.016	0.677	0.032	0.768	0.296	0.077

		E	0.081	0.007	0.144	0.026	0.169	0.062	0.001	0.489	0.002	0.924	0.126	0.009
	15	UE	0.057	0.017	0.080	0.033	0.084	0.052	0.006	0.216	0.010	0.519	0.070	0.020
		E	0.813	0.238	0.608	0.804	0.880	0.754	0.005	0.526	0.048	0.146	0.865	0.316
	20	UE	0.297	0.077	0.407	0.171	0.384	0.277	0.018	0.746	0.038	0.693	0.343	0.092
		E	0.047	0.010	0.072	0.023	0.082	0.040	0.002	0.243	0.005	0.614	0.064	0.012
	25	UE	0.220	0.054	0.309	0.121	0.300	0.201	0.013	0.631	0.026	0.818	0.262	0.064
		E	0.016	0.006	0.022	0.010	0.023	0.015	0.002	0.062	0.004	0.166	0.019	0.006
	30	UE	0.083	0.027	0.115	0.050	0.117	0.077	0.009	0.277	0.016	0.625	0.100	0.030
		E	0.112	0.022	0.169	0.054	0.178	0.097	0.005	0.450	0.010	0.966	0.146	0.026
			Ant Deep											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.956	0.240	0.047	0.750	0.430	0.098	0.167	0.403	0.328	0.034	0.490	0.148
		E	0.225	0.914	0.206	0.197	0.886	0.042	0.820	0.113	0.168	0.008	0.201	0.044
	10	UE	0.832	0.177	0.039	0.944	0.325	0.124	0.126	0.534	0.392	0.051	0.603	0.204
		E	0.616	0.310	0.022	0.473	0.595	0.068	0.167	0.244	0.251	0.017	0.349	0.088
	15	UE	0.967	0.444	0.221	0.807	0.570	0.121	0.403	0.488	0.363	0.059	0.546	0.202
		E	0.966	0.150	0.011	0.738	0.363	0.093	0.070	0.382	0.322	0.029	0.479	0.137
	20	UE	0.019	0.147	0.477	0.030	0.228	0.019	0.034	0.027	0.086	0.002	0.075	0.014
		E	0.642	0.273	0.151	0.782	0.349	0.244	0.250	0.872	0.590	0.182	0.883	0.444
	25	UE	0.073	0.523	0.659	0.081	0.501	0.028	0.418	0.056	0.120	0.004	0.124	0.025
		E	0.205	0.061	0.028	0.292	0.091	0.510	0.052	0.573	0.992	0.483	0.612	0.906
	30	UE	0.956	0.371	0.145	0.779	0.521	0.109	0.319	0.448	0.344	0.046	0.517	0.175
		E	0.285	0.707	0.081	0.242	0.971	0.047	0.538	0.134	0.185	0.009	0.230	0.051
Ant Deep	5	UE	1.000	0.211	0.037	0.785	0.396	0.101	0.141	0.422	0.338	0.035	0.508	0.155
		E	0.211	1.000	0.303	0.185	0.830	0.040	0.939	0.107	0.161	0.007	0.192	0.042
	10	UE	0.037	0.303	1.000	0.050	0.358	0.024	0.130	0.040	0.103	0.003	0.099	0.019
		E	0.785	0.185	0.050	1.000	0.319	0.136	0.139	0.584	0.416	0.062	0.644	0.230
	15	UE	0.396	0.830	0.358	0.319	1.000	0.053	0.770	0.173	0.197	0.013	0.258	0.066
		E	0.101	0.040	0.024	0.136	0.053	1.000	0.037	0.259	0.570	0.921	0.289	0.570
	20	UE	0.141	0.939	0.130	0.139	0.770	0.037	1.000	0.087	0.151	0.006	0.172	0.035
		E	0.422	0.107	0.040	0.584	0.173	0.259	0.087	1.000	0.649	0.181	0.999	0.484
	25	UE	0.338	0.161	0.103	0.416	0.197	0.570	0.151	0.649	1.000	0.570	0.671	0.931
		E	0.035	0.007	0.003	0.062	0.013	0.921	0.006	0.181	0.570	1.000	0.226	0.556
	30	UE	0.508	0.192	0.099	0.644	0.258	0.289	0.172	0.999	0.671	0.226	1.000	0.529
		E	0.155	0.042	0.019	0.230	0.066	0.570	0.035	0.484	0.931	0.556	0.529	1.000
Post Sup	5	UE	0.941	0.253	0.051	0.738	0.443	0.096	0.179	0.396	0.325	0.033	0.484	0.146
		E	0.142	0.861	0.290	0.137	0.725	0.036	0.881	0.084	0.147	0.006	0.166	0.034
	10	UE	0.017	0.127	0.403	0.027	0.210	0.019	0.024	0.025	0.083	0.002	0.072	0.013
		E	0.202	0.983	0.304	0.179	0.817	0.040	0.959	0.104	0.159	0.007	0.188	0.041
	15	UE	0.261	0.072	0.031	0.372	0.111	0.407	0.061	0.706	0.867	0.354	0.737	0.750
		E	0.760	0.225	0.015	0.578	0.484	0.078	0.109	0.296	0.279	0.021	0.400	0.106
	20	UE	0.924	0.357	0.123	0.743	0.520	0.101	0.297	0.416	0.330	0.040	0.493	0.159
		E	0.049	0.009	0.003	0.086	0.018	0.781	0.007	0.248	0.689	0.822	0.301	0.700

	25	UE	0.125	0.691	0.605	0.119	0.610	0.033	0.669	0.074	0.133	0.005	0.147	0.031
		E	0.017	0.006	0.003	0.025	0.008	0.519	0.005	0.061	0.226	0.397	0.076	0.193
	30	UE	0.883	0.434	0.182	0.718	0.585	0.101	0.381	0.410	0.324	0.041	0.482	0.160
		E	0.118	0.021	0.007	0.199	0.041	0.505	0.016	0.490	0.982	0.464	0.545	0.930
Post Deep	5	UE	0.198	0.018	0.003	0.361	0.053	0.283	0.009	0.836	0.722	0.189	0.863	0.545
		E	0.930	0.347	0.153	0.895	0.473	0.132	0.304	0.542	0.393	0.065	0.598	0.223
	10	UE	0.266	0.062	0.023	0.392	0.104	0.357	0.049	0.765	0.806	0.289	0.794	0.670
		E	0.087	0.007	0.001	0.180	0.023	0.420	0.004	0.535	0.933	0.346	0.600	0.811
	15	UE	0.060	0.016	0.008	0.092	0.026	0.919	0.014	0.223	0.594	0.993	0.263	0.590
		E	0.760	0.225	0.015	0.578	0.484	0.078	0.109	0.296	0.279	0.021	0.400	0.106
	20	UE	0.312	0.073	0.026	0.453	0.123	0.317	0.058	0.848	0.746	0.243	0.869	0.597
		E	0.049	0.009	0.003	0.086	0.018	0.781	0.007	0.248	0.689	0.822	0.301	0.700
	25	UE	0.231	0.051	0.018	0.349	0.089	0.383	0.040	0.709	0.846	0.318	0.744	0.717
		E	0.017	0.006	0.003	0.025	0.008	0.519	0.005	0.061	0.226	0.397	0.076	0.193
	30	UE	0.087	0.025	0.012	0.130	0.038	0.816	0.022	0.293	0.688	0.866	0.335	0.703
		E	0.118	0.021	0.007	0.199	0.041	0.505	0.016	0.490	0.982	0.464	0.545	0.930
			Post Sup											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.984	0.167	0.021	0.230	0.250	0.813	0.962	0.047	0.145	0.016	0.919	0.112
		E	0.270	0.754	0.072	0.895	0.076	0.238	0.380	0.010	0.599	0.006	0.461	0.022
	10	UE	0.781	0.125	0.020	0.170	0.335	0.608	0.783	0.072	0.109	0.022	0.755	0.169
		E	0.686	0.181	0.006	0.293	0.152	0.804	0.765	0.023	0.164	0.010	0.835	0.054
	15	UE	0.991	0.387	0.153	0.436	0.319	0.880	0.973	0.082	0.337	0.023	0.939	0.178
		E	0.967	0.080	0.003	0.140	0.234	0.754	0.945	0.040	0.077	0.015	0.900	0.097
	20	UE	0.027	0.114	0.913	0.145	0.022	0.005	0.078	0.002	0.343	0.002	0.124	0.005
		E	0.614	0.241	0.113	0.269	0.630	0.526	0.618	0.243	0.214	0.062	0.602	0.450
	25	UE	0.095	0.577	0.267	0.531	0.041	0.048	0.183	0.005	0.865	0.004	0.251	0.010
		E	0.194	0.051	0.020	0.059	0.846	0.146	0.207	0.614	0.045	0.166	0.207	0.966
	30	UE	0.995	0.306	0.089	0.362	0.285	0.865	0.975	0.064	0.262	0.019	0.936	0.146
		E	0.339	0.515	0.021	0.684	0.089	0.316	0.456	0.012	0.417	0.006	0.540	0.026
Ant Deep	5	UE	0.941	0.142	0.017	0.202	0.261	0.760	0.924	0.049	0.125	0.017	0.883	0.118
		E	0.253	0.861	0.127	0.983	0.072	0.225	0.357	0.009	0.691	0.006	0.434	0.021
	10	UE	0.051	0.290	0.403	0.304	0.031	0.015	0.123	0.003	0.605	0.003	0.182	0.007
		E	0.738	0.137	0.027	0.179	0.372	0.578	0.743	0.086	0.119	0.025	0.718	0.199
	15	UE	0.443	0.725	0.210	0.817	0.111	0.484	0.520	0.018	0.610	0.008	0.585	0.041
		E	0.096	0.036	0.019	0.040	0.407	0.078	0.101	0.781	0.033	0.519	0.101	0.505
	20	UE	0.179	0.881	0.024	0.959	0.061	0.109	0.297	0.007	0.669	0.005	0.381	0.016
		E	0.396	0.084	0.025	0.104	0.706	0.296	0.416	0.248	0.074	0.061	0.410	0.490
	25	UE	0.325	0.147	0.083	0.159	0.867	0.279	0.330	0.689	0.133	0.226	0.324	0.982
		E	0.033	0.006	0.002	0.007	0.354	0.021	0.040	0.822	0.005	0.397	0.041	0.464
	30	UE	0.484	0.166	0.072	0.188	0.737	0.400	0.493	0.301	0.147	0.076	0.482	0.545
		E	0.146	0.034	0.013	0.041	0.750	0.106	0.159	0.700	0.031	0.193	0.160	0.930
Post Sup	5	UE	1.000	0.177	0.024	0.242	0.246	0.832	0.975	0.046	0.153	0.016	0.931	0.110

		E	0.177	1.000	0.093	0.878	0.059	0.123	0.286	0.007	0.778	0.005	0.365	0.016
	10	UE	0.024	0.093	1.000	0.125	0.021	0.004	0.071	0.002	0.307	0.002	0.115	0.004
		E	0.242	0.878	0.125	1.000	0.070	0.211	0.347	0.009	0.702	0.005	0.424	0.020
	15	UE	0.246	0.059	0.021	0.070	1.000	0.183	0.262	0.465	0.052	0.117	0.261	0.793
		E	0.832	0.123	0.004	0.211	0.183	1.000	0.888	0.029	0.116	0.012	0.947	0.069
	20	UE	0.975	0.286	0.071	0.347	0.262	0.888	1.000	0.055	0.244	0.017	0.959	0.128
		E	0.046	0.007	0.002	0.009	0.465	0.029	0.055	1.000	0.007	0.299	0.057	0.605
	25	UE	0.153	0.778	0.307	0.702	0.052	0.116	0.244	0.007	1.000	0.004	0.313	0.014
		E	0.016	0.005	0.002	0.005	0.117	0.012	0.017	0.299	0.004	1.000	0.018	0.151
	30	UE	0.931	0.365	0.115	0.424	0.261	0.947	0.959	0.057	0.313	0.018	1.000	0.131
		E	0.110	0.016	0.004	0.020	0.793	0.069	0.128	0.605	0.014	0.151	0.131	1.000
Post Deep	5	UE	0.182	0.010	0.001	0.016	0.809	0.094	0.220	0.265	0.010	0.062	0.227	0.554
		E	0.887	0.292	0.100	0.339	0.353	0.764	0.877	0.090	0.253	0.025	0.846	0.199
	10	UE	0.249	0.048	0.015	0.060	0.924	0.177	0.270	0.387	0.043	0.094	0.269	0.703
		E	0.080	0.004	0.001	0.007	0.889	0.038	0.104	0.470	0.004	0.108	0.111	0.869
	15	UE	0.056	0.014	0.006	0.016	0.396	0.040	0.063	0.842	0.012	0.413	0.064	0.507
		E	0.832	0.123	0.004	0.211	0.183	1.000	0.888	0.029	0.116	0.012	0.947	0.069
	20	UE	0.293	0.057	0.017	0.071	0.841	0.210	0.314	0.329	0.050	0.080	0.312	0.619
		E	0.046	0.007	0.002	0.009	0.465	0.029	0.055	1.000	0.007	0.299	0.057	0.605
	25	UE	0.216	0.040	0.012	0.050	0.978	0.150	0.237	0.425	0.035	0.103	0.238	0.758
		E	0.016	0.005	0.002	0.005	0.117	0.012	0.017	0.299	0.004	1.000	0.018	0.151
	30	UE	0.082	0.021	0.009	0.025	0.491	0.060	0.090	0.972	0.019	0.344	0.091	0.622
		E	0.110	0.016	0.004	0.020	0.793	0.069	0.128	0.605	0.014	0.151	0.131	1.000

			Post Deep											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.185	0.898	0.253	0.081	0.057	0.813	0.297	0.047	0.220	0.016	0.083	0.112
		E	0.018	0.367	0.065	0.007	0.017	0.238	0.077	0.010	0.054	0.006	0.027	0.022
	10	UE	0.304	0.939	0.350	0.144	0.080	0.608	0.407	0.072	0.309	0.022	0.115	0.169
		E	0.066	0.667	0.144	0.026	0.033	0.804	0.171	0.023	0.121	0.010	0.050	0.054
	15	UE	0.313	0.916	0.335	0.169	0.084	0.880	0.384	0.082	0.300	0.023	0.117	0.178
		E	0.150	0.902	0.234	0.062	0.052	0.754	0.277	0.040	0.201	0.015	0.077	0.097
	20	UE	0.001	0.107	0.016	0.001	0.006	0.005	0.018	0.002	0.013	0.002	0.009	0.005
		E	0.726	0.723	0.677	0.489	0.216	0.526	0.746	0.243	0.631	0.062	0.277	0.450
	25	UE	0.005	0.205	0.032	0.002	0.010	0.048	0.038	0.005	0.026	0.004	0.016	0.010
		E	0.649	0.280	0.768	0.924	0.519	0.146	0.693	0.614	0.818	0.166	0.625	0.966
	30	UE	0.255	0.904	0.296	0.126	0.070	0.865	0.343	0.064	0.262	0.019	0.100	0.146
		E	0.022	0.428	0.077	0.009	0.020	0.316	0.092	0.012	0.064	0.006	0.030	0.026
Ant Deep	5	UE	0.198	0.930	0.266	0.087	0.060	0.760	0.312	0.049	0.231	0.017	0.087	0.118
		E	0.018	0.347	0.062	0.007	0.016	0.225	0.073	0.009	0.051	0.006	0.025	0.021
	10	UE	0.003	0.153	0.023	0.001	0.008	0.015	0.026	0.003	0.018	0.003	0.012	0.007
		E	0.361	0.895	0.392	0.180	0.092	0.578	0.453	0.086	0.349	0.025	0.130	0.199
	15	UE	0.053	0.473	0.104	0.023	0.026	0.484	0.123	0.018	0.089	0.008	0.038	0.041
		E	0.283	0.132	0.357	0.420	0.919	0.078	0.317	0.781	0.383	0.519	0.816	0.505

	20	UE	0.009	0.304	0.049	0.004	0.014	0.109	0.058	0.007	0.040	0.005	0.022	0.016
		E	0.836	0.542	0.765	0.535	0.223	0.296	0.848	0.248	0.709	0.061	0.293	0.490
	25	UE	0.722	0.393	0.806	0.933	0.594	0.279	0.746	0.689	0.846	0.226	0.688	0.982
		E	0.189	0.065	0.289	0.346	0.993	0.021	0.243	0.822	0.318	0.397	0.866	0.464
	30	UE	0.863	0.598	0.794	0.600	0.263	0.400	0.869	0.301	0.744	0.076	0.335	0.545
		E	0.545	0.223	0.670	0.811	0.590	0.106	0.597	0.700	0.717	0.193	0.703	0.930
Post Sup	5	UE	0.182	0.887	0.249	0.080	0.056	0.832	0.293	0.046	0.216	0.016	0.082	0.110
		E	0.010	0.292	0.048	0.004	0.014	0.123	0.057	0.007	0.040	0.005	0.021	0.016
	10	UE	0.001	0.100	0.015	0.001	0.006	0.004	0.017	0.002	0.012	0.002	0.009	0.004
		E	0.016	0.339	0.060	0.007	0.016	0.211	0.071	0.009	0.050	0.005	0.025	0.020
	15	UE	0.809	0.353	0.924	0.889	0.396	0.183	0.841	0.465	0.978	0.117	0.491	0.793
		E	0.094	0.764	0.177	0.038	0.040	1.000	0.210	0.029	0.150	0.012	0.060	0.069
	20	UE	0.220	0.877	0.270	0.104	0.063	0.888	0.314	0.055	0.237	0.017	0.090	0.128
		E	0.265	0.090	0.387	0.470	0.842	0.029	0.329	1.000	0.425	0.299	0.972	0.605
	25	UE	0.010	0.253	0.043	0.004	0.012	0.116	0.050	0.007	0.035	0.004	0.019	0.014
		E	0.062	0.025	0.094	0.108	0.413	0.012	0.080	0.299	0.103	1.000	0.344	0.151
	30	UE	0.227	0.846	0.269	0.111	0.064	0.947	0.312	0.057	0.238	0.018	0.091	0.131
		E	0.554	0.199	0.703	0.869	0.507	0.069	0.619	0.605	0.758	0.151	0.622	1.000
Post Deep	5	UE	1.000	0.354	0.886	0.612	0.240	0.094	0.987	0.265	0.819	0.062	0.321	0.554
		E	0.354	1.000	0.373	0.189	0.093	0.764	0.427	0.090	0.335	0.025	0.129	0.199
	10	UE	0.886	0.373	1.000	0.789	0.334	0.177	0.913	0.387	0.942	0.094	0.424	0.703
		E	0.612	0.189	0.789	1.000	0.399	0.038	0.690	0.470	0.853	0.108	0.508	0.869
	15	UE	0.240	0.093	0.334	0.399	1.000	0.040	0.288	0.842	0.363	0.413	0.881	0.507
		E	0.094	0.764	0.177	0.038	0.040	1.000	0.210	0.029	0.150	0.012	0.060	0.069
	20	UE	0.987	0.427	0.913	0.690	0.288	0.210	1.000	0.329	0.855	0.080	0.370	0.619
		E	0.265	0.090	0.387	0.470	0.842	0.029	0.329	1.000	0.425	0.299	0.972	0.605
	25	UE	0.819	0.335	0.942	0.853	0.363	0.150	0.855	0.425	1.000	0.103	0.458	0.758
		E	0.062	0.025	0.094	0.108	0.413	0.012	0.080	0.299	0.103	1.000	0.344	0.151
	30	UE	0.321	0.129	0.424	0.508	0.881	0.060	0.370	0.972	0.458	0.344	1.000	0.622
		E	0.554	0.199	0.703	0.869	0.507	0.069	0.619	0.605	0.758	0.151	0.622	1.000

BI-LAYER – CIRCUMFERENTIAL DIRECTION (X-DIRECTION)

			Ant Sup											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	1.000	0.891	0.002	0.016	0.009	0.040	0.030	0.029	0.001	0.045	0.008	0.012
		E	0.891	1.000	0.001	0.011	0.008	0.022	0.027	0.020	0.001	0.036	0.007	0.010
	10	UE	0.002	0.001	1.000	0.646	0.177	0.409	0.252	0.941	0.011	0.775	0.084	0.181
		E	0.016	0.011	0.646	1.000	0.351	0.310	0.407	0.650	0.025	0.921	0.164	0.341
	15	UE	0.009	0.008	0.177	0.351	1.000	0.087	0.966	0.195	0.147	0.337	0.567	0.952
		E	0.040	0.022	0.409	0.310	0.087	1.000	0.148	0.566	0.006	0.430	0.046	0.094
	20	UE	0.030	0.027	0.252	0.407	0.966	0.148	1.000	0.261	0.196	0.388	0.632	0.991
		E	0.029	0.020	0.941	0.650	0.195	0.566	0.261	1.000	0.013	0.759	0.093	0.196
	25	UE	0.001	0.001	0.011	0.025	0.147	0.006	0.196	0.013	1.000	0.026	0.399	0.172
		E	0.045	0.036	0.775	0.921	0.337	0.430	0.388	0.759	0.026	1.000	0.160	0.327
	30	UE	0.008	0.007	0.084	0.164	0.567	0.046	0.632	0.093	0.399	0.160	1.000	0.614
		E	0.012	0.010	0.181	0.341	0.952	0.094	0.991	0.196	0.172	0.327	0.614	1.000
Ant Deep	5	UE	0.166	0.077	0.030	0.067	0.025	0.263	0.062	0.136	0.002	0.138	0.017	0.030
		E	0.002	0.002	0.200	0.487	0.699	0.078	0.709	0.241	0.063	0.462	0.341	0.663
	10	UE	0.021	0.017	0.473	0.773	0.526	0.240	0.556	0.487	0.047	0.721	0.257	0.503
		E	0.037	0.030	0.687	0.997	0.381	0.371	0.428	0.681	0.031	0.925	0.182	0.368
	15	UE	0.000	0.000	0.010	0.035	0.279	0.004	0.362	0.014	0.567	0.038	0.704	0.325
		E	0.000	0.000	0.022	0.121	0.774	0.007	0.848	0.039	0.162	0.129	0.681	0.840
	20	UE	0.000	0.000	0.074	0.301	0.854	0.023	0.839	0.115	0.079	0.298	0.420	0.805
		E	0.006	0.004	0.239	0.501	0.735	0.106	0.737	0.270	0.074	0.474	0.370	0.697
	25	UE	0.007	0.006	0.129	0.265	0.843	0.064	0.895	0.144	0.206	0.257	0.698	0.895
		E	0.001	0.001	0.013	0.030	0.169	0.007	0.222	0.015	0.936	0.031	0.443	0.196
	30	UE	0.000	0.000	0.006	0.022	0.189	0.003	0.261	0.009	0.738	0.024	0.542	0.225
		E	0.008	0.007	0.057	0.102	0.346	0.034	0.402	0.062	0.718	0.100	0.678	0.380
Post Sup	5	UE	0.346	0.234	0.023	0.053	0.021	0.197	0.054	0.106	0.002	0.112	0.014	0.025
		E	0.002	0.001	0.176	0.446	0.742	0.068	0.746	0.216	0.069	0.426	0.365	0.703
	10	UE	0.151	0.126	0.561	0.405	0.122	0.983	0.178	0.657	0.008	0.505	0.061	0.125
		E	0.002	0.002	0.110	0.281	0.977	0.047	0.983	0.135	0.133	0.274	0.560	0.970
	15	UE	0.089	0.078	0.870	0.864	0.330	0.536	0.376	0.845	0.028	0.940	0.160	0.319
		E	0.037	0.032	0.483	0.745	0.589	0.268	0.608	0.491	0.062	0.698	0.300	0.562
	20	UE	0.014	0.011	0.291	0.531	0.757	0.145	0.755	0.312	0.086	0.502	0.395	0.719
		E	0.077	0.062	0.873	0.624	0.198	0.683	0.258	0.934	0.014	0.723	0.095	0.198
	25	UE	0.039	0.037	0.174	0.254	0.588	0.116	0.633	0.177	0.538	0.244	0.930	0.623
		E	0.194	0.130	0.087	0.109	0.036	0.418	0.078	0.215	0.003	0.191	0.022	0.041
	30	UE	0.025	0.017	0.965	0.721	0.222	0.500	0.287	0.921	0.015	0.825	0.105	0.221
		E	0.136	0.126	0.725	0.941	0.516	0.487	0.534	0.712	0.063	0.888	0.274	0.494
Post Deep	5	UE	0.139	0.099	0.232	0.201	0.060	0.689	0.110	0.376	0.004	0.300	0.033	0.065
		E	0.060	0.044	0.677	0.475	0.139	0.800	0.201	0.776	0.009	0.587	0.068	0.142
	10	UE	0.068	0.048	0.546	0.391	0.112	0.916	0.173	0.666	0.007	0.504	0.056	0.117

		E	0.329	0.254	0.068	0.089	0.030	0.334	0.068	0.174	0.002	0.160	0.019	0.035
	15	UE	0.037	0.030	0.755	0.932	0.337	0.409	0.389	0.742	0.026	0.989	0.160	0.327
		E	0.013	0.010	0.461	0.787	0.492	0.219	0.530	0.481	0.041	0.732	0.236	0.471
	20	UE	0.030	0.026	0.483	0.760	0.561	0.260	0.584	0.493	0.055	0.711	0.280	0.535
		E	0.069	0.065	0.309	0.432	0.881	0.208	0.916	0.310	0.302	0.413	0.758	0.919
	25	UE	0.007	0.006	0.078	0.151	0.528	0.042	0.593	0.086	0.437	0.147	0.951	0.574
		E	0.198	0.164	0.392	0.294	0.087	0.833	0.139	0.504	0.006	0.391	0.045	0.092
	30	UE	0.037	0.033	0.398	0.622	0.730	0.227	0.729	0.407	0.093	0.586	0.393	0.696
		E	0.016	0.014	0.137	0.237	0.680	0.079	0.736	0.145	0.347	0.229	0.898	0.726

			Ant Deep											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.166	0.002	0.021	0.037	0.000	0.000	0.000	0.006	0.007	0.001	0.000	0.008
		E	0.077	0.002	0.017	0.030	0.000	0.000	0.000	0.004	0.006	0.001	0.000	0.007
	10	UE	0.030	0.200	0.473	0.687	0.010	0.022	0.074	0.239	0.129	0.013	0.006	0.057
		E	0.067	0.487	0.773	0.997	0.035	0.121	0.301	0.501	0.265	0.030	0.022	0.102
	15	UE	0.025	0.699	0.526	0.381	0.279	0.774	0.854	0.735	0.843	0.169	0.189	0.346
		E	0.263	0.078	0.240	0.371	0.004	0.007	0.023	0.106	0.064	0.007	0.003	0.034
	20	UE	0.062	0.709	0.556	0.428	0.362	0.848	0.839	0.737	0.895	0.222	0.261	0.402
		E	0.136	0.241	0.487	0.681	0.014	0.039	0.115	0.270	0.144	0.015	0.009	0.062
	25	UE	0.002	0.063	0.047	0.031	0.567	0.162	0.079	0.074	0.206	0.936	0.738	0.718
		E	0.138	0.462	0.721	0.925	0.038	0.129	0.298	0.474	0.257	0.031	0.024	0.100
	30	UE	0.017	0.341	0.257	0.182	0.704	0.681	0.420	0.370	0.698	0.443	0.542	0.678
		E	0.030	0.663	0.503	0.368	0.325	0.840	0.805	0.697	0.895	0.196	0.225	0.380
Ant Deep	5	UE	1.000	0.011	0.067	0.114	0.001	0.001	0.002	0.022	0.019	0.002	0.001	0.015
		E	0.011	1.000	0.739	0.529	0.108	0.391	0.775	0.973	0.551	0.074	0.067	0.202
	10	UE	0.067	0.739	1.000	0.792	0.078	0.271	0.544	0.732	0.412	0.056	0.049	0.155
		E	0.114	0.529	0.792	1.000	0.046	0.158	0.353	0.536	0.292	0.036	0.029	0.112
	15	UE	0.001	0.108	0.078	0.046	1.000	0.318	0.139	0.131	0.391	0.627	0.785	0.904
		E	0.001	0.391	0.271	0.158	0.318	1.000	0.524	0.450	0.965	0.188	0.206	0.404
	20	UE	0.002	0.775	0.544	0.353	0.139	0.524	1.000	0.822	0.679	0.093	0.086	0.245
		E	0.022	0.973	0.732	0.536	0.131	0.450	0.822	1.000	0.587	0.087	0.083	0.220
	25	UE	0.019	0.551	0.412	0.292	0.391	0.965	0.679	0.587	1.000	0.234	0.274	0.436
		E	0.002	0.074	0.056	0.036	0.627	0.188	0.093	0.087	0.234	1.000	0.805	0.773
	30	UE	0.001	0.067	0.049	0.029	0.785	0.206	0.086	0.083	0.274	0.805	1.000	0.927
		E	0.015	0.202	0.155	0.112	0.904	0.404	0.245	0.220	0.436	0.773	0.927	1.000
Post Sup	5	UE	0.756	0.009	0.055	0.093	0.001	0.000	0.001	0.018	0.016	0.002	0.001	0.013
		E	0.009	0.943	0.692	0.489	0.120	0.435	0.835	0.975	0.588	0.081	0.075	0.216
	10	UE	0.429	0.137	0.309	0.447	0.009	0.022	0.062	0.161	0.091	0.010	0.005	0.042
		E	0.009	0.641	0.466	0.318	0.255	0.774	0.806	0.684	0.853	0.155	0.168	0.336
	15	UE	0.220	0.449	0.684	0.871	0.042	0.139	0.301	0.459	0.254	0.032	0.026	0.099
		E	0.095	0.810	0.953	0.763	0.108	0.349	0.632	0.799	0.471	0.072	0.070	0.181
	20	UE	0.041	0.966	0.743	0.561	0.156	0.498	0.848	0.992	0.614	0.100	0.102	0.237
		E	0.242	0.250	0.474	0.652	0.017	0.050	0.133	0.274	0.148	0.016	0.010	0.062

	25	UE	0.064	0.416	0.335	0.265	0.838	0.684	0.486	0.436	0.690	0.582	0.695	0.787
		E	0.825	0.021	0.097	0.160	0.001	0.001	0.004	0.035	0.027	0.003	0.001	0.018
	30	UE	0.115	0.282	0.542	0.745	0.017	0.050	0.143	0.310	0.164	0.017	0.010	0.068
		E	0.255	0.688	0.890	0.946	0.111	0.323	0.546	0.682	0.418	0.073	0.075	0.169
Post Deep	5	UE	0.561	0.047	0.163	0.257	0.003	0.004	0.013	0.068	0.044	0.005	0.002	0.026
		E	0.247	0.155	0.358	0.519	0.009	0.022	0.066	0.184	0.102	0.011	0.006	0.047
	10	UE	0.294	0.116	0.297	0.442	0.007	0.014	0.044	0.144	0.083	0.009	0.004	0.040
		E	0.974	0.017	0.081	0.134	0.001	0.001	0.004	0.029	0.023	0.003	0.001	0.016
	15	UE	0.123	0.463	0.727	0.934	0.037	0.125	0.295	0.475	0.256	0.030	0.023	0.099
		E	0.051	0.697	0.974	0.807	0.065	0.229	0.493	0.694	0.380	0.048	0.040	0.142
	20	UE	0.085	0.778	0.975	0.778	0.094	0.314	0.593	0.768	0.444	0.064	0.060	0.169
		E	0.115	0.674	0.550	0.446	0.515	0.977	0.775	0.695	0.999	0.334	0.400	0.516
	25	UE	0.016	0.313	0.237	0.167	0.759	0.632	0.385	0.341	0.654	0.483	0.592	0.721
		E	0.555	0.088	0.228	0.341	0.005	0.012	0.034	0.109	0.065	0.007	0.003	0.033
	30	UE	0.087	0.976	0.814	0.643	0.170	0.500	0.810	0.956	0.600	0.107	0.114	0.239
		E	0.033	0.448	0.345	0.256	0.613	0.814	0.541	0.476	0.813	0.385	0.468	0.603
			Post Sup											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.346	0.002	0.151	0.002	0.089	0.037	0.014	0.077	0.039	0.194	0.025	0.136
		E	0.234	0.001	0.126	0.002	0.078	0.032	0.011	0.062	0.037	0.130	0.017	0.126
	10	UE	0.023	0.176	0.561	0.110	0.870	0.483	0.291	0.873	0.174	0.087	0.965	0.725
		E	0.053	0.446	0.405	0.281	0.864	0.745	0.531	0.624	0.254	0.109	0.721	0.941
	15	UE	0.021	0.742	0.122	0.977	0.330	0.589	0.757	0.198	0.588	0.036	0.222	0.516
		E	0.197	0.068	0.983	0.047	0.536	0.268	0.145	0.683	0.116	0.418	0.500	0.487
	20	UE	0.054	0.746	0.178	0.983	0.376	0.608	0.755	0.258	0.633	0.078	0.287	0.534
		E	0.106	0.216	0.657	0.135	0.845	0.491	0.312	0.934	0.177	0.215	0.921	0.712
	25	UE	0.002	0.069	0.008	0.133	0.028	0.062	0.086	0.014	0.538	0.003	0.015	0.063
		E	0.112	0.426	0.505	0.274	0.940	0.698	0.502	0.723	0.244	0.191	0.825	0.888
	30	UE	0.014	0.365	0.061	0.560	0.160	0.300	0.395	0.095	0.930	0.022	0.105	0.274
		E	0.025	0.703	0.125	0.970	0.319	0.562	0.719	0.198	0.623	0.041	0.221	0.494
Ant Deep	5	UE	0.756	0.009	0.429	0.009	0.220	0.095	0.041	0.242	0.064	0.825	0.115	0.255
		E	0.009	0.943	0.137	0.641	0.449	0.810	0.966	0.250	0.416	0.021	0.282	0.688
	10	UE	0.055	0.692	0.309	0.466	0.684	0.953	0.743	0.474	0.335	0.097	0.542	0.890
		E	0.093	0.489	0.447	0.318	0.871	0.763	0.561	0.652	0.265	0.160	0.745	0.946
	15	UE	0.001	0.120	0.009	0.255	0.042	0.108	0.156	0.017	0.838	0.001	0.017	0.111
		E	0.000	0.435	0.022	0.774	0.139	0.349	0.498	0.050	0.684	0.001	0.050	0.323
	20	UE	0.001	0.835	0.062	0.806	0.301	0.632	0.848	0.133	0.486	0.004	0.143	0.546
		E	0.018	0.975	0.161	0.684	0.459	0.799	0.992	0.274	0.436	0.035	0.310	0.682
	25	UE	0.016	0.588	0.091	0.853	0.254	0.471	0.614	0.148	0.690	0.027	0.164	0.418
		E	0.002	0.081	0.010	0.155	0.032	0.072	0.100	0.016	0.582	0.003	0.017	0.073
	30	UE	0.001	0.075	0.005	0.168	0.026	0.070	0.102	0.010	0.695	0.001	0.010	0.075
		E	0.013	0.216	0.042	0.336	0.099	0.181	0.237	0.062	0.787	0.018	0.068	0.169
Post Sup	5	UE	1.000	0.008	0.351	0.007	0.184	0.079	0.034	0.196	0.057	0.644	0.090	0.223

		E	0.008	1.000	0.123	0.688	0.416	0.766	0.986	0.226	0.437	0.018	0.254	0.653
	10	UE	0.351	0.123	1.000	0.079	0.593	0.325	0.196	0.743	0.130	0.539	0.596	0.526
		E	0.007	0.688	0.079	1.000	0.274	0.538	0.713	0.143	0.587	0.015	0.158	0.473
	15	UE	0.184	0.416	0.593	0.274	1.000	0.664	0.483	0.803	0.237	0.278	0.906	0.847
		E	0.079	0.766	0.325	0.538	0.664	1.000	0.803	0.476	0.367	0.126	0.539	0.858
	20	UE	0.034	0.986	0.196	0.713	0.483	0.803	1.000	0.310	0.451	0.059	0.351	0.690
		E	0.196	0.226	0.743	0.143	0.803	0.476	0.310	1.000	0.174	0.326	0.864	0.684
	25	UE	0.057	0.437	0.130	0.587	0.237	0.367	0.451	0.174	1.000	0.074	0.191	0.331
		E	0.644	0.018	0.539	0.015	0.278	0.126	0.059	0.326	0.074	1.000	0.184	0.297
	30	UE	0.090	0.254	0.596	0.158	0.906	0.539	0.351	0.864	0.191	0.184	1.000	0.758
		E	0.223	0.653	0.526	0.473	0.847	0.858	0.690	0.684	0.331	0.297	0.758	1.000
Post Deep	5	UE	0.440	0.041	0.744	0.030	0.396	0.191	0.098	0.490	0.093	0.727	0.329	0.384
		E	0.194	0.138	0.853	0.088	0.681	0.373	0.224	0.864	0.145	0.355	0.704	0.591
	10	UE	0.229	0.103	0.949	0.067	0.602	0.318	0.183	0.765	0.129	0.420	0.599	0.534
		E	0.834	0.015	0.458	0.013	0.238	0.107	0.050	0.273	0.067	0.835	0.150	0.264
	15	UE	0.099	0.426	0.487	0.273	0.929	0.703	0.504	0.707	0.244	0.174	0.809	0.896
		E	0.040	0.649	0.296	0.427	0.693	0.927	0.709	0.470	0.319	0.079	0.539	0.907
	20	UE	0.070	0.733	0.321	0.506	0.676	0.978	0.775	0.479	0.352	0.116	0.544	0.874
		E	0.103	0.702	0.229	0.892	0.399	0.589	0.709	0.303	0.733	0.132	0.333	0.525
	25	UE	0.014	0.336	0.056	0.520	0.147	0.277	0.365	0.087	0.970	0.020	0.096	0.254
		E	0.456	0.078	0.848	0.052	0.480	0.250	0.142	0.600	0.109	0.681	0.451	0.442
	30	UE	0.074	0.934	0.273	0.690	0.561	0.865	0.952	0.397	0.443	0.112	0.447	0.748
		E	0.028	0.476	0.098	0.681	0.224	0.390	0.498	0.145	0.849	0.041	0.161	0.350

			Post Deep											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.139	0.060	0.068	0.329	0.037	0.013	0.030	0.069	0.007	0.198	0.037	0.016
		E	0.099	0.044	0.048	0.254	0.030	0.010	0.026	0.065	0.006	0.164	0.033	0.014
	10	UE	0.232	0.677	0.546	0.068	0.755	0.461	0.483	0.309	0.078	0.392	0.398	0.137
		E	0.201	0.475	0.391	0.089	0.932	0.787	0.760	0.432	0.151	0.294	0.622	0.237
	15	UE	0.060	0.139	0.112	0.030	0.337	0.492	0.561	0.881	0.528	0.087	0.730	0.680
		E	0.689	0.800	0.916	0.334	0.409	0.219	0.260	0.208	0.042	0.833	0.227	0.079
	20	UE	0.110	0.201	0.173	0.068	0.389	0.530	0.584	0.916	0.593	0.139	0.729	0.736
		E	0.376	0.776	0.666	0.174	0.742	0.481	0.493	0.310	0.086	0.504	0.407	0.145
	25	UE	0.004	0.009	0.007	0.002	0.026	0.041	0.055	0.302	0.437	0.006	0.093	0.347
		E	0.300	0.587	0.504	0.160	0.989	0.732	0.711	0.413	0.147	0.391	0.586	0.229
	30	UE	0.033	0.068	0.056	0.019	0.160	0.236	0.280	0.758	0.951	0.045	0.393	0.898
		E	0.065	0.142	0.117	0.035	0.327	0.471	0.535	0.919	0.574	0.092	0.696	0.726
Ant Deep	5	UE	0.561	0.247	0.294	0.974	0.123	0.051	0.085	0.115	0.016	0.555	0.087	0.033
		E	0.047	0.155	0.116	0.017	0.463	0.697	0.778	0.674	0.313	0.088	0.976	0.448
	10	UE	0.163	0.358	0.297	0.081	0.727	0.974	0.975	0.550	0.237	0.228	0.814	0.345
		E	0.257	0.519	0.442	0.134	0.934	0.807	0.778	0.446	0.167	0.341	0.643	0.256
	15	UE	0.003	0.009	0.007	0.001	0.037	0.065	0.094	0.515	0.759	0.005	0.170	0.613
		E	0.004	0.022	0.014	0.001	0.125	0.229	0.314	0.977	0.632	0.012	0.500	0.814

	20	UE	0.013	0.066	0.044	0.004	0.295	0.493	0.593	0.775	0.385	0.034	0.810	0.541
		E	0.068	0.184	0.144	0.029	0.475	0.694	0.768	0.695	0.341	0.109	0.956	0.476
	25	UE	0.044	0.102	0.083	0.023	0.256	0.380	0.444	0.999	0.654	0.065	0.600	0.813
		E	0.005	0.011	0.009	0.003	0.030	0.048	0.064	0.334	0.483	0.007	0.107	0.385
	30	UE	0.002	0.006	0.004	0.001	0.023	0.040	0.060	0.400	0.592	0.003	0.114	0.468
		E	0.026	0.047	0.040	0.016	0.099	0.142	0.169	0.516	0.721	0.033	0.239	0.603
Post Sup	5	UE	0.440	0.194	0.229	0.834	0.099	0.040	0.070	0.103	0.014	0.456	0.074	0.028
		E	0.041	0.138	0.103	0.015	0.426	0.649	0.733	0.702	0.336	0.078	0.934	0.476
	10	UE	0.744	0.853	0.949	0.458	0.487	0.296	0.321	0.229	0.056	0.848	0.273	0.098
		E	0.030	0.088	0.067	0.013	0.273	0.427	0.506	0.892	0.520	0.052	0.690	0.681
	15	UE	0.396	0.681	0.602	0.238	0.929	0.693	0.676	0.399	0.147	0.480	0.561	0.224
		E	0.191	0.373	0.318	0.107	0.703	0.927	0.978	0.589	0.277	0.250	0.865	0.390
	20	UE	0.098	0.224	0.183	0.050	0.504	0.709	0.775	0.709	0.365	0.142	0.952	0.498
		E	0.490	0.864	0.765	0.273	0.707	0.470	0.479	0.303	0.087	0.600	0.397	0.145
	25	UE	0.093	0.145	0.129	0.067	0.244	0.319	0.352	0.733	0.970	0.109	0.443	0.849
		E	0.727	0.355	0.420	0.835	0.174	0.079	0.116	0.132	0.020	0.681	0.112	0.041
	30	UE	0.329	0.704	0.599	0.150	0.809	0.539	0.544	0.333	0.096	0.451	0.447	0.161
		E	0.384	0.591	0.534	0.264	0.896	0.907	0.874	0.525	0.254	0.442	0.748	0.350
Post Deep	5	UE	1.000	0.560	0.649	0.602	0.281	0.143	0.181	0.166	0.031	0.906	0.165	0.058
		E	0.560	1.000	0.890	0.291	0.568	0.344	0.370	0.255	0.063	0.689	0.312	0.110
	10	UE	0.649	0.890	1.000	0.343	0.484	0.280	0.313	0.229	0.052	0.779	0.267	0.093
		E	0.602	0.291	0.343	1.000	0.145	0.065	0.098	0.119	0.018	0.580	0.097	0.036
	15	UE	0.281	0.568	0.484	0.145	1.000	0.738	0.716	0.415	0.147	0.373	0.590	0.229
		E	0.143	0.344	0.280	0.065	0.738	1.000	0.950	0.530	0.216	0.212	0.786	0.322
	20	UE	0.181	0.370	0.313	0.098	0.716	0.950	1.000	0.571	0.258	0.243	0.841	0.369
		E	0.166	0.255	0.229	0.119	0.415	0.530	0.571	1.000	0.720	0.193	0.688	0.849
	25	UE	0.031	0.063	0.052	0.018	0.147	0.216	0.258	0.720	1.000	0.042	0.365	0.853
		E	0.906	0.689	0.779	0.580	0.373	0.212	0.243	0.193	0.042	1.000	0.212	0.075
	30	UE	0.165	0.312	0.267	0.097	0.590	0.786	0.841	0.688	0.365	0.212	1.000	0.490
		E	0.058	0.110	0.093	0.036	0.229	0.322	0.369	0.849	0.853	0.075	0.490	1.000

BI-LAYER – LONGITUDINAL DIRECTION (Y-DIRECTION)

			Ant Sup											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	1.000	0.332	0.300	0.351	0.264	0.657	0.117	0.813	0.219	0.408	0.299	0.986
		E	0.332	1.000	0.890	0.933	0.748	0.344	0.130	0.393	0.546	0.842	0.920	0.207
	10	UE	0.300	0.890	1.000	0.992	0.851	0.280	0.153	0.348	0.647	0.751	0.952	0.175
		E	0.351	0.933	0.992	1.000	0.892	0.423	0.387	0.422	0.784	0.818	0.979	0.254
	15	UE	0.264	0.748	0.851	0.892	1.000	0.217	0.216	0.299	0.822	0.639	0.782	0.144
		E	0.657	0.344	0.280	0.423	0.217	1.000	0.028	0.835	0.119	0.514	0.259	0.581
	20	UE	0.117	0.130	0.153	0.387	0.216	0.028	1.000	0.107	0.112	0.164	0.064	0.037
		E	0.813	0.393	0.348	0.422	0.299	0.835	0.107	1.000	0.235	0.499	0.346	0.792
	25	UE	0.219	0.546	0.647	0.784	0.822	0.119	0.112	0.235	1.000	0.490	0.502	0.098
		E	0.408	0.842	0.751	0.818	0.639	0.514	0.164	0.499	0.490	1.000	0.764	0.298
	30	UE	0.299	0.920	0.952	0.979	0.782	0.259	0.064	0.346	0.502	0.764	1.000	0.167
		E	0.986	0.207	0.175	0.254	0.144	0.581	0.037	0.792	0.098	0.298	0.167	1.000
Ant Deep	5	UE	0.167	0.323	0.381	0.578	0.497	0.072	0.527	0.168	0.496	0.318	0.262	0.066
		E	0.439	0.680	0.577	0.704	0.462	0.564	0.057	0.542	0.279	0.878	0.568	0.318
	10	UE	0.172	0.316	0.377	0.609	0.511	0.064	0.284	0.172	0.454	0.323	0.216	0.065
		E	0.390	0.912	0.825	0.872	0.716	0.484	0.220	0.475	0.578	0.944	0.845	0.283
	15	UE	0.610	0.505	0.438	0.542	0.365	0.892	0.091	0.766	0.262	0.656	0.432	0.535
		E	0.449	0.648	0.545	0.681	0.431	0.584	0.048	0.556	0.249	0.851	0.531	0.328
	20	UE	0.503	0.047	0.039	0.068	0.031	0.167	0.008	0.313	0.020	0.075	0.036	0.419
		E	0.120	0.162	0.190	0.395	0.257	0.036	0.962	0.112	0.199	0.183	0.108	0.041
	25	UE	0.394	0.049	0.042	0.063	0.035	0.140	0.012	0.246	0.026	0.070	0.040	0.324
		E	0.382	0.028	0.023	0.043	0.019	0.106	0.005	0.220	0.012	0.047	0.021	0.298
	30	UE	0.565	0.116	0.103	0.133	0.090	0.271	0.037	0.398	0.071	0.153	0.101	0.506
		E	0.925	0.178	0.152	0.219	0.126	0.499	0.035	0.703	0.088	0.255	0.145	0.893
Post Sup	5	UE	0.164	0.311	0.367	0.566	0.479	0.069	0.557	0.164	0.473	0.308	0.250	0.065
		E	0.463	0.610	0.509	0.654	0.399	0.613	0.041	0.575	0.222	0.817	0.491	0.343
	10	UE	0.145	0.203	0.241	0.502	0.340	0.040	0.507	0.138	0.190	0.235	0.104	0.049
		E	0.114	0.108	0.126	0.372	0.183	0.023	0.972	0.101	0.061	0.149	0.042	0.034
	15	UE	0.192	0.447	0.517	0.656	0.638	0.116	0.517	0.204	0.706	0.407	0.424	0.089
		E	0.186	0.400	0.473	0.656	0.611	0.088	0.338	0.193	0.655	0.379	0.339	0.078
	20	UE	0.145	0.238	0.281	0.493	0.374	0.052	0.733	0.141	0.331	0.250	0.175	0.053
		E	0.262	0.727	0.820	0.866	0.956	0.226	0.304	0.298	0.898	0.626	0.757	0.147
	25	UE	0.318	0.871	0.952	0.956	0.938	0.355	0.372	0.377	0.819	0.757	0.916	0.214
		E	0.766	0.123	0.105	0.156	0.087	0.360	0.025	0.549	0.060	0.180	0.100	0.710
	30	UE	0.871	0.249	0.223	0.270	0.195	0.523	0.084	0.681	0.159	0.313	0.222	0.840
		E	0.753	0.096	0.080	0.132	0.064	0.324	0.015	0.526	0.041	0.151	0.074	0.690
Post Deep	5	UE	0.170	0.337	0.397	0.592	0.517	0.075	0.496	0.173	0.524	0.329	0.277	0.069
		E	0.431	0.703	0.599	0.721	0.481	0.547	0.062	0.531	0.297	0.899	0.592	0.309
	10	UE	0.133	0.163	0.193	0.453	0.275	0.033	0.688	0.124	0.129	0.201	0.076	0.043

		E	0.148	0.224	0.266	0.514	0.368	0.045	0.530	0.143	0.257	0.249	0.132	0.052
	15	UE	0.251	0.689	0.783	0.843	0.922	0.204	0.300	0.283	0.932	0.595	0.712	0.136
		E	0.431	0.877	0.802	0.845	0.708	0.567	0.273	0.529	0.596	0.992	0.819	0.339
	20	UE	0.499	0.698	0.620	0.701	0.531	0.690	0.157	0.620	0.411	0.848	0.625	0.407
		E	0.822	0.063	0.048	0.112	0.036	0.314	0.004	0.566	0.017	0.122	0.040	0.759
	25	UE	0.224	0.010	0.008	0.018	0.007	0.044	0.002	0.112	0.004	0.018	0.007	0.153
		E	0.858	0.146	0.111	0.235	0.080	0.649	0.006	0.909	0.032	0.272	0.091	0.835
	30	UE	0.276	0.015	0.012	0.024	0.010	0.061	0.002	0.144	0.006	0.026	0.011	0.198
		E	0.555	0.056	0.047	0.080	0.038	0.196	0.010	0.355	0.025	0.089	0.043	0.473
			Ant Deep											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.167	0.439	0.172	0.390	0.610	0.449	0.503	0.120	0.394	0.382	0.565	0.925
		E	0.323	0.680	0.316	0.912	0.505	0.648	0.047	0.162	0.049	0.028	0.116	0.178
	10	UE	0.381	0.577	0.377	0.825	0.438	0.545	0.039	0.190	0.042	0.023	0.103	0.152
		E	0.578	0.704	0.609	0.872	0.542	0.681	0.068	0.395	0.063	0.043	0.133	0.219
	15	UE	0.497	0.462	0.511	0.716	0.365	0.431	0.031	0.257	0.035	0.019	0.090	0.126
		E	0.072	0.564	0.064	0.484	0.892	0.584	0.167	0.036	0.140	0.106	0.271	0.499
	20	UE	0.527	0.057	0.284	0.220	0.091	0.048	0.008	0.962	0.012	0.005	0.037	0.035
		E	0.168	0.542	0.172	0.475	0.766	0.556	0.313	0.112	0.246	0.220	0.398	0.703
	25	UE	0.496	0.279	0.454	0.578	0.262	0.249	0.020	0.199	0.026	0.012	0.071	0.088
		E	0.318	0.878	0.323	0.944	0.656	0.851	0.075	0.183	0.070	0.047	0.153	0.255
	30	UE	0.262	0.568	0.216	0.845	0.432	0.531	0.036	0.108	0.040	0.021	0.101	0.145
		E	0.066	0.318	0.065	0.283	0.535	0.328	0.419	0.041	0.324	0.298	0.506	0.893
Ant Deep	5	UE	1.000	0.162	0.863	0.390	0.172	0.143	0.014	0.566	0.019	0.009	0.054	0.060
		E	0.162	1.000	0.145	0.822	0.725	0.969	0.076	0.077	0.073	0.047	0.162	0.272
	10	UE	0.863	0.145	1.000	0.404	0.172	0.125	0.014	0.392	0.019	0.008	0.055	0.060
		E	0.390	0.822	0.404	1.000	0.619	0.796	0.072	0.237	0.068	0.045	0.147	0.243
	15	UE	0.172	0.725	0.172	0.619	1.000	0.745	0.162	0.102	0.135	0.105	0.256	0.462
		E	0.143	0.969	0.125	0.796	0.745	1.000	0.079	0.067	0.075	0.048	0.166	0.280
	20	UE	0.014	0.076	0.014	0.072	0.162	0.079	1.000	0.009	0.790	0.810	0.992	0.508
		E	0.566	0.077	0.392	0.237	0.102	0.067	0.009	1.000	0.013	0.005	0.039	0.038
	25	UE	0.019	0.073	0.019	0.068	0.135	0.075	0.790	0.013	1.000	0.963	0.808	0.391
		E	0.009	0.047	0.008	0.045	0.105	0.048	0.810	0.005	0.963	1.000	0.829	0.371
	30	UE	0.054	0.162	0.055	0.147	0.256	0.166	0.992	0.039	0.808	0.829	1.000	0.583
		E	0.060	0.272	0.060	0.243	0.462	0.280	0.508	0.038	0.391	0.371	0.583	1.000
Post Sup	5	UE	0.971	0.155	0.829	0.379	0.168	0.137	0.014	0.592	0.019	0.008	0.053	0.059
		E	0.127	0.929	0.108	0.764	0.774	0.960	0.083	0.058	0.078	0.050	0.172	0.292
	10	UE	0.842	0.088	0.543	0.307	0.127	0.074	0.011	0.591	0.015	0.006	0.046	0.046
		E	0.471	0.046	0.183	0.204	0.083	0.038	0.007	0.980	0.012	0.004	0.036	0.032
	15	UE	0.892	0.252	0.979	0.477	0.227	0.230	0.019	0.541	0.024	0.012	0.064	0.079
		E	0.807	0.202	0.898	0.458	0.204	0.179	0.017	0.406	0.022	0.010	0.060	0.070
	20	UE	0.798	0.116	0.625	0.315	0.137	0.101	0.012	0.742	0.016	0.007	0.047	0.049
		E	0.584	0.463	0.617	0.697	0.364	0.435	0.033	0.334	0.036	0.020	0.090	0.128

	25	UE	0.586	0.629	0.619	0.816	0.481	0.604	0.054	0.385	0.052	0.033	0.117	0.185
		E	0.042	0.189	0.042	0.172	0.338	0.195	0.676	0.027	0.523	0.516	0.730	0.813
	30	UE	0.120	0.336	0.124	0.300	0.487	0.344	0.626	0.086	0.493	0.488	0.676	0.930
		E	0.028	0.156	0.027	0.144	0.306	0.161	0.670	0.017	0.514	0.505	0.727	0.798
Post Deep	5	UE	0.968	0.169	0.903	0.402	0.178	0.150	0.015	0.540	0.020	0.009	0.055	0.062
		E	0.172	0.976	0.156	0.842	0.708	0.945	0.074	0.083	0.071	0.045	0.158	0.264
	10	UE	0.696	0.070	0.378	0.267	0.110	0.058	0.009	0.727	0.014	0.006	0.042	0.041
		E	0.870	0.100	0.627	0.320	0.134	0.085	0.011	0.596	0.016	0.007	0.047	0.048
	15	UE	0.597	0.427	0.632	0.669	0.342	0.400	0.030	0.334	0.034	0.018	0.085	0.119
		E	0.428	0.890	0.446	0.959	0.686	0.867	0.095	0.283	0.084	0.061	0.170	0.292
	20	UE	0.278	0.941	0.284	0.802	0.813	0.965	0.115	0.170	0.100	0.073	0.200	0.350
		E	0.011	0.121	0.009	0.118	0.301	0.125	0.546	0.006	0.414	0.389	0.630	0.884
	25	UE	0.003	0.018	0.003	0.018	0.045	0.018	0.531	0.002	0.759	0.701	0.582	0.202
		E	0.020	0.281	0.015	0.259	0.590	0.292	0.270	0.009	0.215	0.177	0.384	0.723
	30	UE	0.004	0.025	0.004	0.025	0.062	0.026	0.629	0.003	0.862	0.810	0.671	0.255
		E	0.017	0.091	0.017	0.086	0.189	0.094	0.927	0.011	0.727	0.740	0.945	0.567

			Post Sup											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.164	0.463	0.145	0.114	0.192	0.186	0.145	0.262	0.318	0.766	0.871	0.753
		E	0.311	0.610	0.203	0.108	0.447	0.400	0.238	0.727	0.871	0.123	0.249	0.096
	10	UE	0.367	0.509	0.241	0.126	0.517	0.473	0.281	0.820	0.952	0.105	0.223	0.080
		E	0.566	0.654	0.502	0.372	0.656	0.656	0.493	0.866	0.956	0.156	0.270	0.132
	15	UE	0.479	0.399	0.340	0.183	0.638	0.611	0.374	0.956	0.938	0.087	0.195	0.064
		E	0.069	0.613	0.040	0.023	0.116	0.088	0.052	0.226	0.355	0.360	0.523	0.324
	20	UE	0.557	0.041	0.507	0.972	0.517	0.338	0.733	0.304	0.372	0.025	0.084	0.015
		E	0.164	0.575	0.138	0.101	0.204	0.193	0.141	0.298	0.377	0.549	0.681	0.526
	25	UE	0.473	0.222	0.190	0.061	0.706	0.655	0.331	0.898	0.819	0.060	0.159	0.041
		E	0.308	0.817	0.235	0.149	0.407	0.379	0.250	0.626	0.757	0.180	0.313	0.151
	30	UE	0.250	0.491	0.104	0.042	0.424	0.339	0.175	0.757	0.916	0.100	0.222	0.074
		E	0.065	0.343	0.049	0.034	0.089	0.078	0.053	0.147	0.214	0.710	0.840	0.690
Ant Deep	5	UE	0.971	0.127	0.842	0.471	0.892	0.807	0.798	0.584	0.586	0.042	0.120	0.028
		E	0.155	0.929	0.088	0.046	0.252	0.202	0.116	0.463	0.629	0.189	0.336	0.156
	10	UE	0.829	0.108	0.543	0.183	0.979	0.898	0.625	0.617	0.619	0.042	0.124	0.027
		E	0.379	0.764	0.307	0.204	0.477	0.458	0.315	0.697	0.816	0.172	0.300	0.144
	15	UE	0.168	0.774	0.127	0.083	0.227	0.204	0.137	0.364	0.481	0.338	0.487	0.306
		E	0.137	0.960	0.074	0.038	0.230	0.179	0.101	0.435	0.604	0.195	0.344	0.161
	20	UE	0.014	0.083	0.011	0.007	0.019	0.017	0.012	0.033	0.054	0.676	0.626	0.670
		E	0.592	0.058	0.591	0.980	0.541	0.406	0.742	0.334	0.385	0.027	0.086	0.017
	25	UE	0.019	0.078	0.015	0.012	0.024	0.022	0.016	0.036	0.052	0.523	0.493	0.514
		E	0.008	0.050	0.006	0.004	0.012	0.010	0.007	0.020	0.033	0.516	0.488	0.505
	30	UE	0.053	0.172	0.046	0.036	0.064	0.060	0.047	0.090	0.117	0.730	0.676	0.727
		E	0.059	0.292	0.046	0.032	0.079	0.070	0.049	0.128	0.185	0.813	0.930	0.798
Post Sup	5	UE	1.000	0.122	0.880	0.503	0.868	0.779	0.828	0.567	0.573	0.041	0.118	0.027

		E	0.122	1.000	0.063	0.032	0.210	0.159	0.089	0.406	0.576	0.203	0.355	0.169
	10	UE	0.880	0.063	1.000	0.386	0.757	0.581	0.895	0.451	0.498	0.032	0.104	0.020
		E	0.503	0.032	0.386	1.000	0.480	0.273	0.688	0.275	0.354	0.023	0.081	0.014
	15	UE	0.868	0.210	0.757	0.480	1.000	0.956	0.729	0.706	0.675	0.055	0.140	0.039
		E	0.779	0.159	0.581	0.273	0.956	1.000	0.609	0.698	0.673	0.049	0.135	0.033
	20	UE	0.828	0.089	0.895	0.688	0.729	0.609	1.000	0.462	0.492	0.035	0.104	0.023
		E	0.567	0.406	0.451	0.275	0.706	0.698	0.462	1.000	0.908	0.089	0.194	0.067
	25	UE	0.573	0.576	0.498	0.354	0.675	0.673	0.492	0.908	1.000	0.130	0.242	0.107
		E	0.041	0.203	0.032	0.023	0.055	0.049	0.035	0.089	0.130	1.000	0.907	0.993
	30	UE	0.118	0.355	0.104	0.081	0.140	0.135	0.104	0.194	0.242	0.907	1.000	0.898
		E	0.027	0.169	0.020	0.014	0.039	0.033	0.023	0.067	0.107	0.993	0.898	1.000
Post Deep	5	UE	0.939	0.133	0.800	0.439	0.918	0.840	0.767	0.604	0.602	0.043	0.123	0.029
		E	0.165	0.905	0.095	0.050	0.265	0.214	0.123	0.481	0.646	0.184	0.329	0.151
	10	UE	0.733	0.050	0.738	0.593	0.650	0.452	0.949	0.381	0.443	0.029	0.095	0.018
		E	0.906	0.073	0.970	0.434	0.779	0.628	0.883	0.474	0.512	0.034	0.106	0.022
	15	UE	0.579	0.370	0.453	0.268	0.725	0.718	0.468	0.970	0.882	0.082	0.186	0.061
		E	0.418	0.838	0.360	0.260	0.500	0.490	0.359	0.691	0.794	0.210	0.337	0.184
	20	UE	0.270	0.995	0.216	0.146	0.347	0.326	0.224	0.522	0.642	0.252	0.392	0.222
		E	0.010	0.133	0.006	0.004	0.019	0.013	0.008	0.040	0.082	0.900	0.981	0.886
	25	UE	0.003	0.019	0.002	0.001	0.004	0.003	0.002	0.007	0.013	0.303	0.301	0.289
		E	0.019	0.311	0.009	0.005	0.039	0.024	0.014	0.090	0.180	0.539	0.703	0.505
	30	UE	0.004	0.027	0.003	0.002	0.006	0.005	0.003	0.010	0.018	0.373	0.363	0.359
		E	0.017	0.099	0.013	0.009	0.023	0.020	0.014	0.040	0.064	0.743	0.684	0.739

			Post Deep											
			5		10		15		20		25		30	
			UE	E	UE	E	UE	E	UE	E	UE	E	UE	E
Ant Sup	5	UE	0.170	0.431	0.133	0.148	0.251	0.431	0.499	0.822	0.224	0.858	0.276	0.555
		E	0.337	0.703	0.163	0.224	0.689	0.877	0.698	0.063	0.010	0.146	0.015	0.056
	10	UE	0.397	0.599	0.193	0.266	0.783	0.802	0.620	0.048	0.008	0.111	0.012	0.047
		E	0.592	0.721	0.453	0.514	0.843	0.845	0.701	0.112	0.018	0.235	0.024	0.080
	15	UE	0.517	0.481	0.275	0.368	0.922	0.708	0.531	0.036	0.007	0.080	0.010	0.038
		E	0.075	0.547	0.033	0.045	0.204	0.567	0.690	0.314	0.044	0.649	0.061	0.196
	20	UE	0.496	0.062	0.688	0.530	0.300	0.273	0.157	0.004	0.002	0.006	0.002	0.010
		E	0.173	0.531	0.124	0.143	0.283	0.529	0.620	0.566	0.112	0.909	0.144	0.355
	25	UE	0.524	0.297	0.129	0.257	0.932	0.596	0.411	0.017	0.004	0.032	0.006	0.025
		E	0.329	0.899	0.201	0.249	0.595	0.992	0.848	0.122	0.018	0.272	0.026	0.089
	30	UE	0.277	0.592	0.076	0.132	0.712	0.819	0.625	0.040	0.007	0.091	0.011	0.043
		E	0.069	0.309	0.043	0.052	0.136	0.339	0.407	0.759	0.153	0.835	0.198	0.473
Ant Deep	5	UE	0.968	0.172	0.696	0.870	0.597	0.428	0.278	0.011	0.003	0.020	0.004	0.017
		E	0.169	0.976	0.070	0.100	0.427	0.890	0.941	0.121	0.018	0.281	0.025	0.091
	10	UE	0.903	0.156	0.378	0.627	0.632	0.446	0.284	0.009	0.003	0.015	0.004	0.017
		E	0.402	0.842	0.267	0.320	0.669	0.959	0.802	0.118	0.018	0.259	0.025	0.086
	15	UE	0.178	0.708	0.110	0.134	0.342	0.686	0.813	0.301	0.045	0.590	0.062	0.189
		E	0.150	0.945	0.058	0.085	0.400	0.867	0.965	0.125	0.018	0.292	0.026	0.094

	20	UE	0.015	0.074	0.009	0.011	0.030	0.095	0.115	0.546	0.531	0.270	0.629	0.927
		E	0.540	0.083	0.727	0.596	0.334	0.283	0.170	0.006	0.002	0.009	0.003	0.011
	25	UE	0.020	0.071	0.014	0.016	0.034	0.084	0.100	0.414	0.759	0.215	0.862	0.727
		E	0.009	0.045	0.006	0.007	0.018	0.061	0.073	0.389	0.701	0.177	0.810	0.740
	30	UE	0.055	0.158	0.042	0.047	0.085	0.170	0.200	0.630	0.582	0.384	0.671	0.945
		E	0.062	0.264	0.041	0.048	0.119	0.292	0.350	0.884	0.202	0.723	0.255	0.567
Post Sup	5	UE	0.939	0.165	0.733	0.906	0.579	0.418	0.270	0.010	0.003	0.019	0.004	0.017
		E	0.133	0.905	0.050	0.073	0.370	0.838	0.995	0.133	0.019	0.311	0.027	0.099
	10	UE	0.800	0.095	0.738	0.970	0.453	0.360	0.216	0.006	0.002	0.009	0.003	0.013
		E	0.439	0.050	0.593	0.434	0.268	0.260	0.146	0.004	0.001	0.005	0.002	0.009
	15	UE	0.918	0.265	0.650	0.779	0.725	0.500	0.347	0.019	0.004	0.039	0.006	0.023
		E	0.840	0.214	0.452	0.628	0.718	0.490	0.326	0.013	0.003	0.024	0.005	0.020
	20	UE	0.767	0.123	0.949	0.883	0.468	0.359	0.224	0.008	0.002	0.014	0.003	0.014
		E	0.604	0.481	0.381	0.474	0.970	0.691	0.522	0.040	0.007	0.090	0.010	0.040
	25	UE	0.602	0.646	0.443	0.512	0.882	0.794	0.642	0.082	0.013	0.180	0.018	0.064
		E	0.043	0.184	0.029	0.034	0.082	0.210	0.252	0.900	0.303	0.539	0.373	0.743
	30	UE	0.123	0.329	0.095	0.106	0.186	0.337	0.392	0.981	0.301	0.703	0.363	0.684
		E	0.029	0.151	0.018	0.022	0.061	0.184	0.222	0.886	0.289	0.505	0.359	0.739
Post Deep	5	UE	1.000	0.180	0.656	0.831	0.618	0.439	0.286	0.011	0.003	0.021	0.004	0.018
		E	0.180	1.000	0.076	0.108	0.445	0.907	0.923	0.116	0.017	0.270	0.024	0.089
	10	UE	0.656	0.076	1.000	0.750	0.379	0.322	0.189	0.005	0.002	0.007	0.003	0.011
		E	0.831	0.108	0.750	1.000	0.479	0.371	0.226	0.007	0.002	0.010	0.003	0.013
	15	UE	0.618	0.445	0.379	0.479	1.000	0.666	0.497	0.035	0.007	0.077	0.009	0.036
		E	0.439	0.907	0.322	0.371	0.666	1.000	0.858	0.166	0.026	0.339	0.035	0.112
	20	UE	0.286	0.923	0.189	0.226	0.497	0.858	1.000	0.205	0.031	0.421	0.042	0.135
		E	0.011	0.116	0.005	0.007	0.035	0.166	0.205	1.000	0.199	0.534	0.258	0.615
	25	UE	0.003	0.017	0.002	0.002	0.007	0.026	0.031	0.199	1.000	0.077	0.884	0.472
		E	0.021	0.270	0.007	0.010	0.077	0.339	0.421	0.534	0.077	1.000	0.105	0.315
	30	UE	0.004	0.024	0.003	0.003	0.009	0.035	0.042	0.258	0.884	0.105	1.000	0.565
		E	0.018	0.089	0.011	0.013	0.036	0.112	0.135	0.615	0.472	0.315	0.565	1.000

SHEAR LOADING – CIRCUMFERENTIAL DIRECTION (X-DIRECTION)

		Ant Sup						Ant Deep					
		5	10	15	20	25	30	5	10	15	20	25	30
Ant Sup	5	1.000	0.027	0.011	0.007	0.004	0.015	0.016	0.006	0.005	0.000	0.000	0.000
	10	0.027	1.000	0.126	0.115	0.296	0.195	0.235	0.181	0.177	0.003	0.009	0.001
	15	0.011	0.126	1.000	0.957	0.405	0.771	0.663	0.647	0.633	0.841	0.450	0.113
	20	0.007	0.115	0.957	1.000	0.410	0.803	0.689	0.672	0.657	0.771	0.394	0.090
	25	0.004	0.296	0.405	0.410	1.000	0.592	0.698	0.664	0.672	0.091	0.064	0.010
	30	0.015	0.195	0.771	0.803	0.592	1.000	0.885	0.880	0.866	0.535	0.268	0.056
Ant Deep	5	0.016	0.235	0.663	0.689	0.698	0.885	1.000	0.997	0.990	0.398	0.198	0.038
	10	0.006	0.181	0.647	0.672	0.664	0.880	0.997	1.000	0.986	0.340	0.169	0.029
	15	0.005	0.177	0.633	0.657	0.672	0.866	0.990	0.986	1.000	0.318	0.159	0.027
	20	0.000	0.003	0.841	0.771	0.091	0.535	0.398	0.340	0.318	1.000	0.403	0.064
	25	0.000	0.009	0.450	0.394	0.064	0.268	0.198	0.169	0.159	0.403	1.000	0.315
	30	0.000	0.001	0.113	0.090	0.010	0.056	0.038	0.029	0.027	0.064	0.315	1.000
Post Sup	5	0.671	0.017	0.009	0.006	0.003	0.012	0.013	0.004	0.004	0.000	0.000	0.000
	10	0.822	0.034	0.012	0.008	0.005	0.017	0.018	0.007	0.006	0.000	0.000	0.000
	15	0.009	0.398	0.347	0.348	0.867	0.511	0.606	0.566	0.570	0.067	0.051	0.008
	20	0.014	0.397	0.377	0.380	0.912	0.548	0.645	0.610	0.616	0.095	0.063	0.010
	25	0.006	0.171	0.667	0.694	0.639	0.903	0.973	0.973	0.959	0.364	0.179	0.031
	30	0.016	0.784	0.171	0.160	0.428	0.263	0.317	0.260	0.257	0.007	0.014	0.002
Post Deep	5	0.016	0.166	0.896	0.934	0.496	0.876	0.766	0.755	0.741	0.706	0.369	0.087
	10	0.000	0.003	0.389	0.331	0.036	0.213	0.149	0.119	0.110	0.301	0.943	0.318
	15	0.005	0.119	0.842	0.880	0.472	0.910	0.786	0.773	0.757	0.595	0.289	0.057
	20	0.006	0.211	0.566	0.585	0.759	0.788	0.909	0.897	0.909	0.245	0.128	0.021
	25	0.000	0.026	0.883	0.826	0.201	0.613	0.490	0.453	0.435	0.960	0.451	0.089
	30	0.016	0.211	0.731	0.762	0.631	0.958	0.927	0.925	0.911	0.485	0.242	0.049

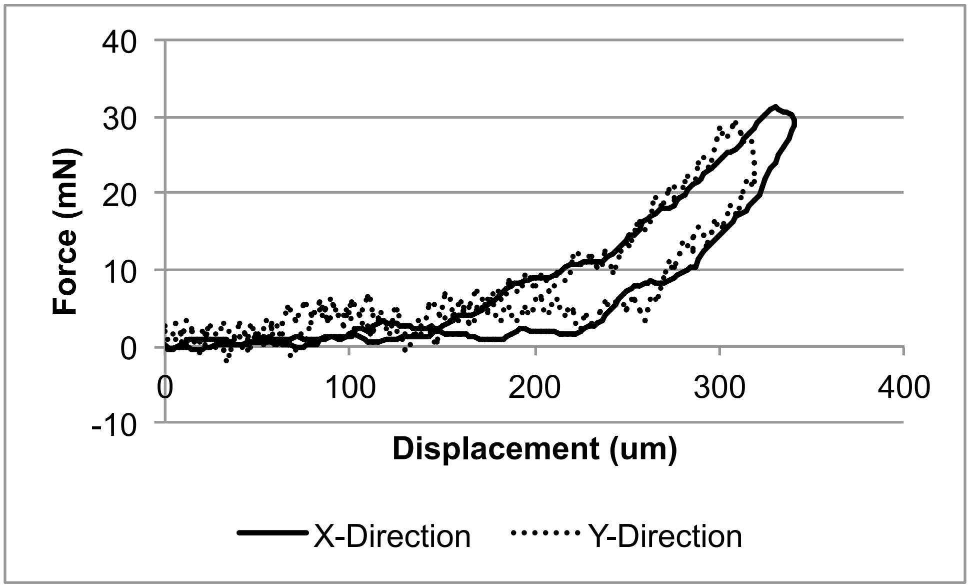
		Post Sup						Post Deep					
		5	10	15	20	25	30	5	10	15	20	25	30
Ant Sup	5	0.671	0.822	0.009	0.014	0.006	0.016	0.016	0.000	0.005	0.006	0.000	0.016
	10	0.017	0.034	0.398	0.397	0.171	0.784	0.166	0.003	0.119	0.211	0.026	0.211
	15	0.009	0.012	0.347	0.377	0.667	0.171	0.896	0.389	0.842	0.566	0.883	0.731
	20	0.006	0.008	0.348	0.380	0.694	0.160	0.934	0.331	0.880	0.585	0.826	0.762
	25	0.003	0.005	0.867	0.912	0.639	0.428	0.496	0.036	0.472	0.759	0.201	0.631
	30	0.012	0.017	0.511	0.548	0.903	0.263	0.876	0.213	0.910	0.788	0.613	0.958
Ant Deep	5	0.013	0.018	0.606	0.645	0.973	0.317	0.766	0.149	0.786	0.909	0.490	0.927
	10	0.004	0.007	0.566	0.610	0.973	0.260	0.755	0.119	0.773	0.897	0.453	0.925
	15	0.004	0.006	0.570	0.616	0.959	0.257	0.741	0.110	0.757	0.909	0.435	0.911
	20	0.000	0.000	0.067	0.095	0.364	0.007	0.706	0.301	0.595	0.245	0.960	0.485
	25	0.000	0.000	0.051	0.063	0.179	0.014	0.369	0.943	0.289	0.128	0.451	0.242
	30	0.000	0.000	0.008	0.010	0.031	0.002	0.087	0.318	0.057	0.021	0.089	0.049
Post Sup	5	1.000	0.504	0.006	0.010	0.004	0.010	0.013	0.000	0.004	0.004	0.000	0.013
	10	0.504	1.000	0.011	0.016	0.007	0.020	0.017	0.000	0.006	0.007	0.000	0.018

	15	0.006	0.011	1.000	0.962	0.543	0.550	0.428	0.027	0.397	0.649	0.160	0.546
	20	0.010	0.016	0.962	1.000	0.587	0.538	0.460	0.036	0.436	0.695	0.191	0.584
	25	0.004	0.007	0.543	0.587	1.000	0.246	0.777	0.128	0.798	0.870	0.475	0.948
	30	0.010	0.020	0.550	0.538	0.246	1.000	0.221	0.006	0.172	0.304	0.044	0.283
Post Deep	5	0.013	0.017	0.428	0.460	0.777	0.221	1.000	0.310	0.955	0.671	0.763	0.836
	10	0.000	0.000	0.027	0.036	0.128	0.006	0.310	1.000	0.227	0.085	0.369	0.189
	15	0.004	0.006	0.397	0.436	0.798	0.172	0.955	0.227	1.000	0.675	0.679	0.865
	20	0.004	0.007	0.649	0.695	0.870	0.304	0.671	0.085	0.675	1.000	0.364	0.832
	25	0.000	0.000	0.160	0.191	0.475	0.044	0.763	0.369	0.679	0.364	1.000	0.568
	30	0.013	0.018	0.546	0.584	0.948	0.283	0.836	0.189	0.865	0.832	0.568	1.000

APPENDIX D – Raw Data Example from Material Testing

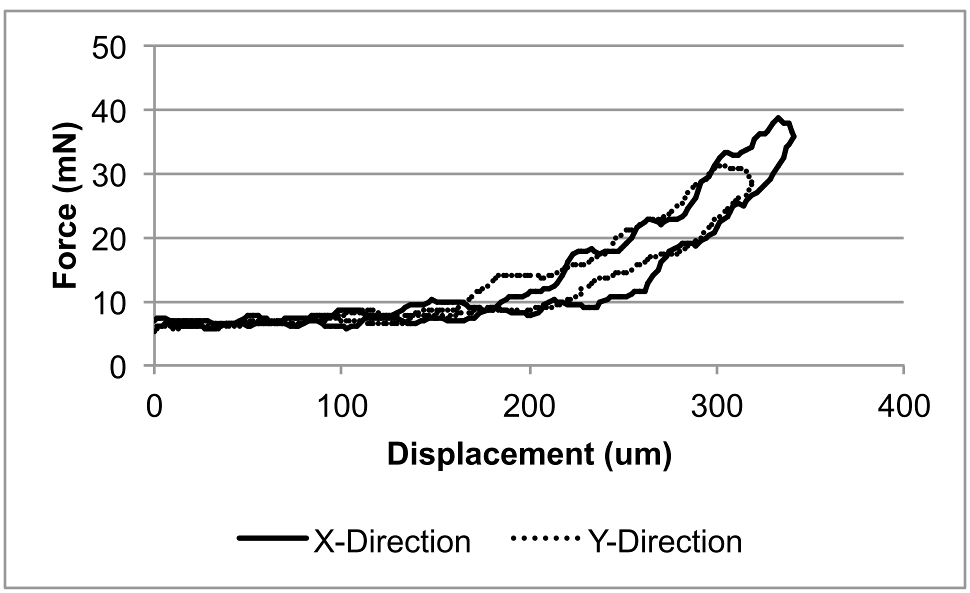
Note: Loading profiles shown are samples. Systematic differences in the loading profiles were not found between annular locations.

Single Layer Bi-axial Testing – Target Strain = 10%
One Cycle



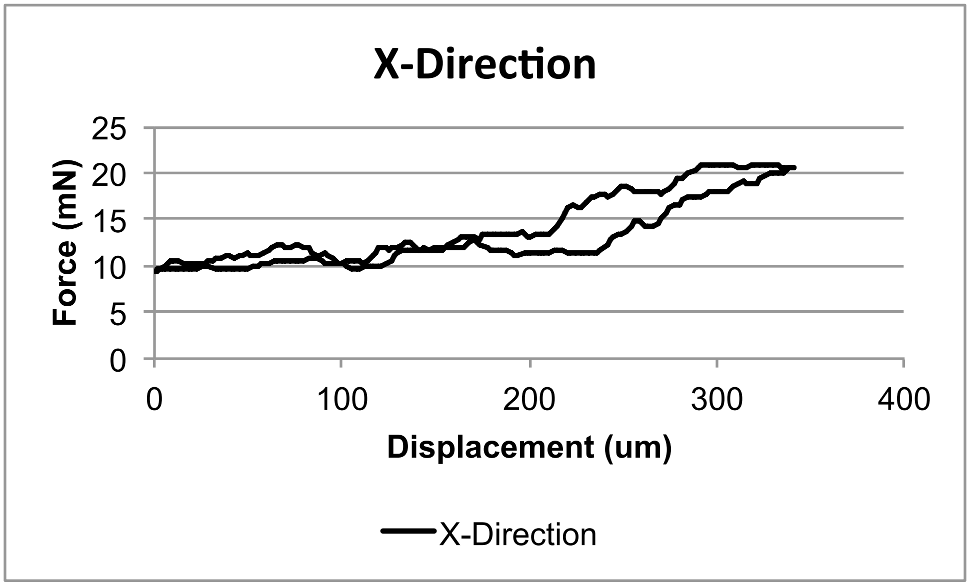
*Posterior Superficial

Double Layer Bi-Axial Testing – Target Strain = 10%
One Cycle



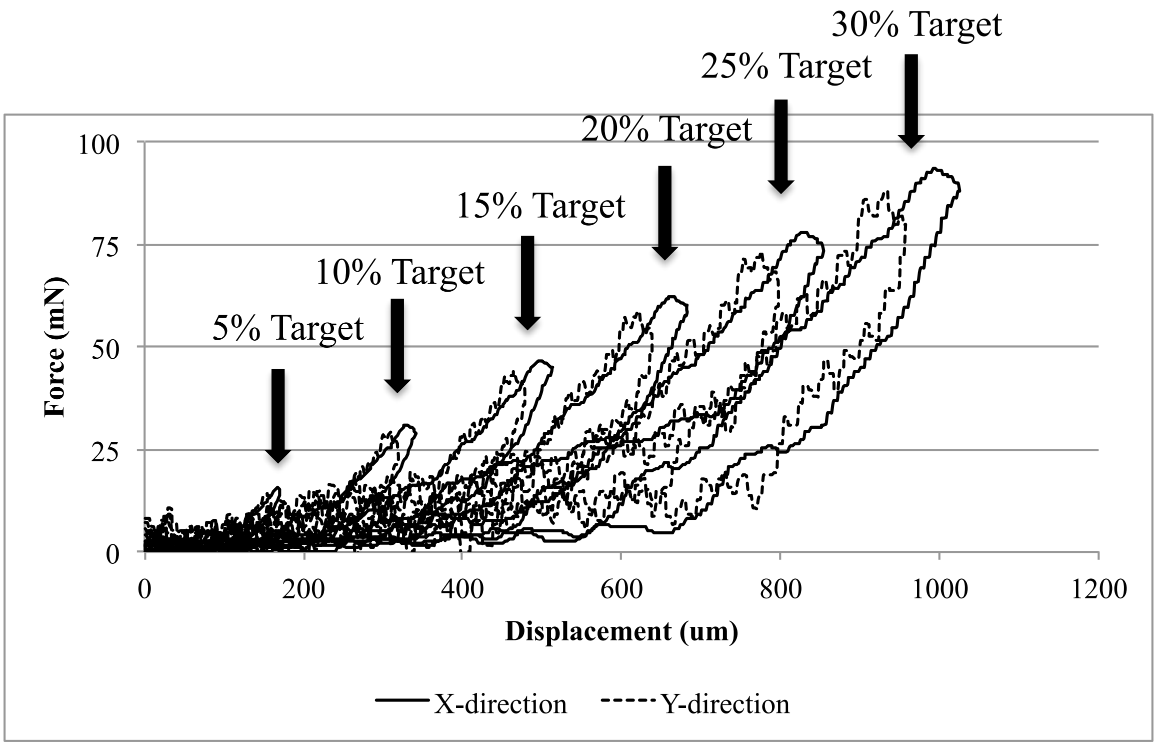
*Posterior Deep

Lap Testing – Target Strain = 10%
One Cycle



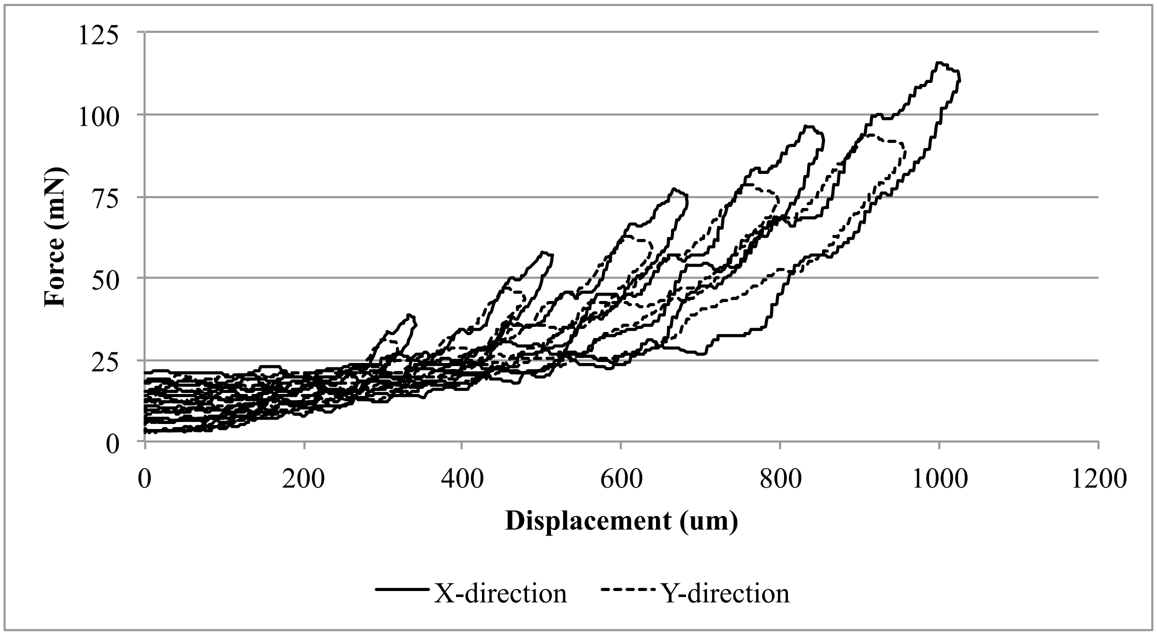
*Anterior Superficial

Single Layer Bi-axial Testing – 3rd Cycle for Each Target Strain Magnitude
Full Protocol



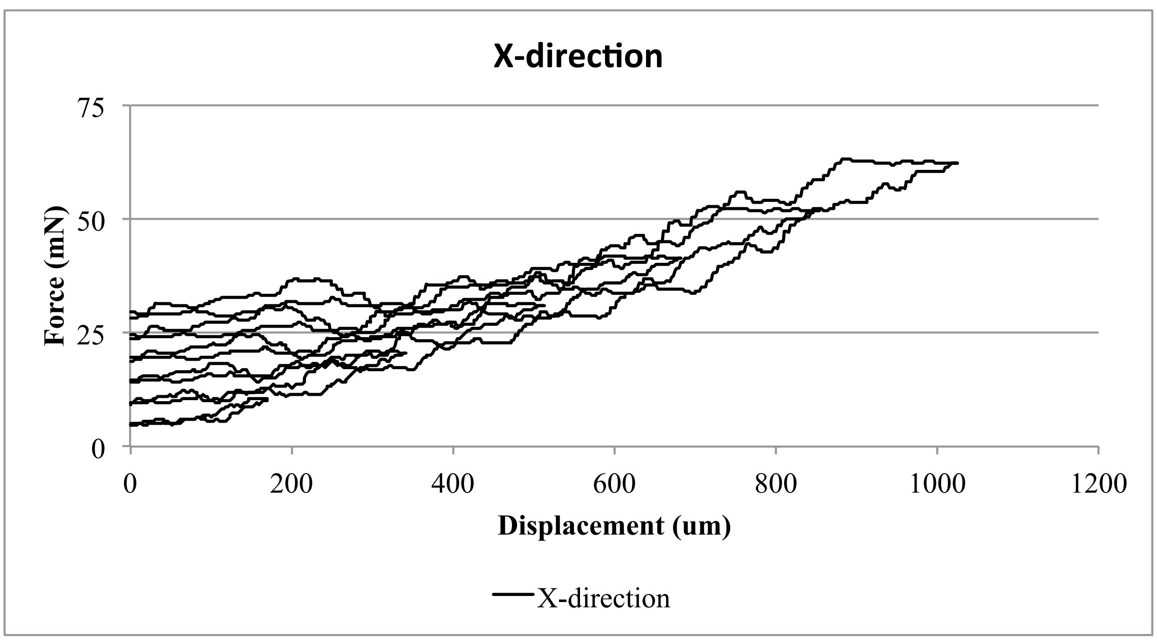
*Posterior Superficial

Double Layer Bi-Axial Testing – 3rd Cycle for Each Target Strain Magnitude
Full Protocol



*Posterior Deep

Lap Testing – 3rd Cycle for Each Target Strain Magnitude
Full Protocol



*Anterior Superficial