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Post fatigue changes in the stability of cervical spine

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POST FATIGUE CHANGES IN THE STABILITY OF CERVICAL SPINE

Majed M. Zreiqat

Dissertation submitted to the
Benjamin M. Statler College of Engineering and Mineral Resources at
West Virginia University

In partial fulfillment of the requirement for the degree of

Doctor of Philosophy in
IMSE/Occupational Safety and Health

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2014

Keywords: Cervical spine, stability, fatigue, flexion relaxation, sudden perturbations, neck
musculoskeletal disorders

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ABSTRACT

POST FATIGUE CHANGES IN THE STABILITY OF CERVICAL SPINE

Majed M. Zreiqat

Musculoskeletal disorders (MSDs) of the neck or cervical spine are a common problem in the modern workforce. An annual prevalence of 30% to 50% for neck pain among the general adult population was reported by the Task Force of Bone and Joint Decade on Neck Pain. Physical work demands, such as sustained static postures, sub-maximal repetitive arm exertions, and forceful arm exertions are consistently identified as possible risk factors for cervical spine MSDs. Most of these exertions induce neck muscle fatigue which may affect the stability of the cervical spine. A less stable spine can be both a cause and consequence of spinal pain. The effect of muscle fatigue on the stability of the cervical spine is currently not well understood. The objective in this study was to quantify the post-fatigue changes and recovery of the cervical spine's stability. Specifically, the flexion-relaxation phenomenon (FRP) and sudden perturbations (SP) procedures were used to study the variables that influence the stability of the cervical spine. The FRP explains the synergistic load sharing between the muscles and viscoelastic elements (ligaments, discs, capsules, and fascia). The SP protocol allows quantification of the muscle reflex responses necessary to maintain spinal stability.

Twenty human participants (10 male and 10 female) were recruited for data collection and the Sorenson protocol was utilized to induce neck muscle fatigue. Surface electromyography and optical motion capture systems were used to measure neck muscle activation and head-neck posture, respectively. A six degree of freedom force torque sensor was used to record the force profile data during the SP procedure.

Localized muscle fatigue significantly reduced the flexion-relaxation ratio from 4.88 ± 0.81 pre-fatigue to 3.33 ± 0.57 post-fatigue. A post-fatigue decrease was also observed in the onset and offset angles by about 16% and 5%, respectively, resulting in an expansion of the myoelectric silence period by 17.2%. The intrinsic stiffness of cervical spine was reduced from 975.75 ± 85.87 Kg/sec² pre-fatigue to 826.31 ± 90.76 Kg/sec² post-fatigue. The corresponding change in the effective stiffness was from 1404.64 ± 122.31 Kg/sec² to 1086.53 ± 123.73 Kg/sec². The temporal parameters related to the reflexive response of the neck extensors were also affected by fatigue. Onset delay, time to peak and peak to peak values increased from 92.81 ± 21.06 to 127.07 ± 30.45 msec, 231.08 ± 39.55 to 325.54 ± 49.99 msec, and 89.36 ± 36.40 to 178.22 ± 49.28 msec, respectively, post-fatigue. A slight but non-significant decrease in the reflex gain and reflex amplitude was also observed post-fatigue.

Post-fatigue recovery of the FRP and SP parameters was measured during the rest period at 15, 30, 45 and 60 minutes. Majority of the parameters showed close to full recovery in the first 30 minutes. A recovery of about 79% to 95% was observed during the first 15 minutes and during the next 15 minutes a recovery of about 5% to 11% was observed.

The results of this study seem to indicate that the muscle fatigue affect the stability of cervical spine by causing an early shift in the load-sharing towards the passive tissues and by delaying the muscle reflex response. These findings could be used as valuable markers to assess post-fatigue changes in the neuromuscular control of the cervical spine and to derive possible MSD development pathways.

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TABLE OF CONTENTS

ABSTRACT.....	
ACKNOWLEDGEMENTS	i
TABLE OF CONTENTS	ii
LIST OF FIGURES	vii
LIST OF TABLES	ix
CHAPTER ONE: INTRODUCTION	1
CHAPTER TWO: LITERATURE REVIEW	5
2.1 Anatomy of cervical spine.....	5
2.2 Flexion-Relaxation Phenomenon	9
2.2.1 Lumbar spine FRP	9
2.2.1.1 Effect of load and speed.....	9
2.2.1.2 Effect of posture	10
2.2.1.3 Effect of cyclic loading.....	11
2.2.1.4 Creep Effect	12
2.2.1.5 Effect of fatigue	12
2.2.1.6 Symptomatic and a symptomatic people	13
2.2.1.7 General.....	14
2.2.1.8 Muscles recruitment patterns in lumbar spine FRP	15
2.2.2 Cervical spine FRP	16
2.2.2.1 Effect of load and speed.....	16
2.2.2.2 Effect of posture	17
2.2.2.3 General.....	18
2.3 Sudden Perturbation	19
2.3.1 Muscle reflex in lumbar spine	19
2.3.1.1 Load, preload effect	20

2.3.1.2 Posture effect	21
2.2.1.3 Fatigue and creep effect.....	24
2.2.1.4 Gender effect	24
2.2.1.5 Muscle reflex in lumbar spine in people with back pain	25
2.3.2 Muscle reflex in neck/cervical spine	26
2.3.3 Muscle reflex in lower limbs	29
2.3.4 Muscle reflex in upper limbs	31
CHAPTER THREE: RATIONALE AND OBJECTIVES	33
CHAPTER FOUR: METHODOLOGY	37
4.1 Participants	37
4.2 Apparatus/tools.....	40
4.2.1 Custom-built sudden perturbation workstation	40
4.2.2 Electromyography (EMG) system.....	42
4.2.3 Optical Motion Capture System	43
4.2.4 Force/Torque (F/T) Sensor System	44
4.2.4.1 Mini 45 F/T Sensor	44
4.2.4.2 Mux Box	45
4.2.4.3 F/T Controller	45
4.3 Experimental Design	46
4.3.1 Flexion Relaxation Phenomenon.....	46
4.3.2 Sudden perturbation procedure.....	46
4.3.3 Fatigue protocol.....	47
4.4 Data Collection.....	48
4.4.1 Participant orientation & measurement	48
4.4.2 EMG data collection preparation.....	48
4.4.3 Actual Data Collection	49
4.5 Data Processing and Analysis	49

4.5.3 Dependent variables	51
4.5.4 Recovery	56
4.5.5 Statistical Analysis	56
CHAPTER FIVE: PRELIMINARY STUDIES	58
CHAPTER SIX: RESULTS.....	64
6.1 Sorenson protocol and fatigue:.....	64
6.1.1 Median frequency analysis	64
6.1.2 Power analysis	66
6.2 Flexion-relaxation phenomenon (FRP).....	67
6.2.1 Side effect.....	67
6.2.2 Gender effect	68
6.2.3 Fatigue effect.....	68
6.2.4 Fatigue-gender interaction effect.....	70
6.3 SP results	69
6.3.1 Side effect.....	70
6.3.2 Gender effect	71
6.3.3 Fatigue effect.....	72
6.3.4 Fatigue-gender interaction effect.....	72
6.3.5 Muscle stiffness	74
6.4 Recovery data	75
6.4.1 FRP recovery data	75
6.4.2 SP recovery data	78
CHAPTER SEVEN: DISCUSSION AND CONCLUSIONS	80
7.2 Flexion-relaxation phenomenon.....	80
7.2.1 Effect of muscular fatigue	80
7.2.2 Effect of gender	83

7.3 Sudden perturbation	84
7.3.1 Effect of muscular fatigue	84
7.3.1.1 SP Temporal parameters	84
7.3.1.2 Relationship between TTP and PTP	85
7.3.1.3 Reflex gain and reflex amplitude	86
7.3.1.4 Stiffness	87
7.3.2 Effect of gender	87
7.4 Recovery	88
7.5 Limitations and future research	90
7.6 Practical Implication	92
7.7 Conclusions	92
BIBLIOGRAPHY	94
APPENDICES	108
Appendix A: IRB Approval	109
Appendix B: Physical Activity Readiness Questionnaire	114
Appendix C: Participants data	115
Appendix D: Normality test for FRP parameters	117
Appendix E: Normality test for SP parameters	119
Appendix F: Levene's test of equality of error variances for FRP parameters	121
Appendix G: Levene's Test of Equality of Error Variances for SP parameters	122
Appendix H: Median frequency and power spectrum statistical analysis	123
Appendix I: Multivariate analysis for FRP parameters	126
Appendix J: Multivariate analysis for SP parameters– side effect	129
Appendix K: Multivariate analysis for FRP parameters - fatigue & gender effect	132
Appendix L: Multivariate analysis for SP parameters– fatigue & gender effects	133
Appendix M: Statistical analysis for recovery data	135

Appendix N: Processed FRP data145

Appendix O: Processed SP data163

LIST OF FIGURES

Figure 1: Lateral view of the cervical vertebrae. Retrieved from Taiwan Spine center website Center TS (2014).....	5
Figure 2: Cervical spine ligaments: (A) Anterior longitudinal ligament, (B) Posterior longitudinal ligament and (C) Ligaments of the cervical spine. Adapted from Gilroy et al. (2008).....	6
Figure 3: The sternocleidomastoid (a) and trapezius (b) muscles. Adapted from Tortora (2005)	8
Figure 4: Cervical paraspinal muscle group. Adapted from Gilroy et al. (Gilroy et al. 2008).....	8
Figure 5: Custom-built workstation: (a) column assembly base, (b) four-point harness (c) wooden chair, (d) head rest, (e) steel cable, and (f) adjustable headband	
Figure 6: Column assembly column: (a) pulley, (b) measuring tape, (c) force sensor, (d) electromagnet, (e) load, (f) preload, and (g) mux box	
Figure 7: Column assembly base components: (a) pulley, (b) force sensor, (c) electromagnet, (d) load, and (e) preload	
Figure 8: Bagnoli system components: (a) main amplifier unit, (b) input modules, and (c) surface electrodes.....	
Figure 9: Bagnoli system components: (a) reference electrode with tip and banana connectors, (b) input cable, and (c) power supply unit	
Figure 10: EMG surface electrodes diagram	43
Figure 11: Infrared camera & retro-reflective markers.....	
Figure 12: Data-station	
Figure 13: F/T Sensor system components.....	
Figure 14: F/T sensor system component: (a) F/T sensor mini 45, (b) 16-pin twist-to-lock connector, and (c) mux-box	
Figure 15: EMG and kinematic data during cervical a flexion-extension trial and the corresponding FR phases and parameters.....	47
Figure 16: Sorenson protocol.....	
Figure 17: Pendulum.....	
Figure 18: Borg's CR-10 scale.	48
Figure 19: Different view angles of markers and electrode placement (a) rear view, (b) front view, and (c) side view	

Figure 20: (a) raw markers data, and (b) processed markers data	
Figure 21: Muscle reflex parameters	53
Figure 22: Manikin during the sudden perturbation procedure	58
Figure 23: Correlation coefficient and RMSE for force data for the two days.....	60
Figure 24: Correlation coefficient and RMSE for displacement data for the two days.....	60
Figure 25: Raw EMG and motion data for one of the participants.....	62
Figure 26: Pre- & post-fatigue FRR. Error bars represent 1 SD. Bars at the end of the.....	63
Figure 27: Pre- & post-fatigue average onset and offset angles.	63
Figure 28: Onset and offset shifts and silent period expansion.	63
Figure 29: Fatigue-gender interaction effect on frequency power spectrum: (a) median frequency, power of 8-16 Hz, 16-32 Hz and 250-500 Hz frequency bands and (b) power of 32-63 Hz, 63-125 Hz and 125-250 Hz frequency bands.....	65
Figure 30: Fatigue-gender interaction effect on FRP parameters: (a) FRR, (b) onset and offset angles, and (c) temporal variables.	70
Figure 31: Fatigue-gender interaction effect on FRP parameters: (a) muscle reflex temporal parameters; (b) muscle reflex magnitude-related parameters.	73
Figure 32: Fatigue-gender interaction effect on the stiffness	74
Figure 33: Post hoc pairwise comparison for the FRR, onset and offset angles	76
Figure 34: Post hoc pairwise comparison for FRP temporal parameters.....	76
Figure 35: Post hoc pairwise comparison for the OD & TTP.....	78
Figure 36: Post hoc pairwise comparison for the PTP & stiffness	78
Figure 37: Relationship between TTP and PPT.....	86

LIST OF TABLES

Table 1: Participants demographic data	37
Table 2: δ & σ^2 values for the FRP parameters	38
Table 3: FRR power and sample size calculations	39
Table 4: Onset angle power and sample size calculations	39
Table 5: Offset angle power and sample size calculations	39
Table 6: F/T sensor-two calibration settings	45
Table 7: Statistical analysis between the two days	59
Table 8: Correlation Coefficient for the manikin's displacement data	61
Table 9: Correlation coefficient for the manikin's force data	61
Table 10: Effect of side, fatigue and gender on the median frequency	65
Table 11: Side effect on the power of different frequency bands	66
Table 12: Fatigue effect on the power of different frequency bands	67
Table 13: Gender effect on the power of different frequency bands	67
Table 14: Side effect on FRP parameters	68
Table 15: Gender effect on FRP parameters	69
Table 16: Fatigue effect on FRP parameters	69
Table 17: Side effect on SP parameters	71
Table 18: Gender effect on SP parameters	71
Table 19: Fatigue effect on SP parameters	72
Table 20: Gender and fatigue effect on stiffness	74
Table 21: FRP parameters recovery data	77
Table 22: Gender effect on the FRP parameters recovery (Data represented as % Recovery) ...	77
Table 23: SP recovery data	79
Table 24: Gender effect on SP parameters recovery (Data represented as % Recovery)	79
Table 25: Normality test for FRP parameters - fatigue	117
Table 26: Normality test for FRP parameters - gender	118
Table 27: Normality test for SP temporal and magnitude parameters residuals - fatigue	119
Table 28: Normality test for stiffness residual - fatigue	119
Table 29: Normality test for SP temporal and magnitude parameters residuals - gender	120
Table 30: Normality test for stiffness residuals - gender	120

Table 31: Levene's test for FRP parameters	121
Table 32: Levene's test - Pooled side	121
Table 33: Levene's test for SP parameters	122
Table 34: Levene's test for SP parameters – pooled side.....	122
Table 35: Levene's test for stiffness.....	122
Table 36: Univariate analysis for FRR – side effect.....	126
Table 37: Univariate analysis for onset angle – side effect	126
Table 38: Univariate analysis for offset angle – side effect.....	127
Table 39: Univariate analysis for T1 – side effect.....	127
Table 40: Univariate analysis for T2 – side effect.....	128
Table 41: Univariate analysis for Expansion – side effect	128
Table 42: Univariate analysis for OD – side effect.....	129
Table 43: Univariate analysis for TTP– side effect	129
Table 44: Univariate analysis for PTP – side effect	130
Table 45: Univariate analysis for RG – side effect.....	130
Table 46: Univariate analysis for RA– side effect.....	131
Table 47: Multivariate analysis for FRP parameters – fatigue, gender and their interaction effect	132
Table 48: Multivariate analysis for SP parameters – fatigue, gender and their interaction effect	133
Table 49: Multivariate analysis for stiffness – fatigue, gender and their interaction effects	134
Table 50: Normality test for FRP recovery data	135
Table 51: Levene's test for FRP parameters recovery data	136
Table 52: Post hoc pairwise comparison for FRP parameters recovery data	137
Table 53: Multivariate analysis for FRP recovery data – gender effect	140
Table 54: Multivariate analysis for FRP recovery data –fatigue, gender and their interaction effects.....	140
Table 55: Normality test for SP parameters recovery data	141
Table 56: Levene's test for SP parameters recovery data.....	141
Table 57: Post hoc pairwise comparison for SP parameters recovery data	142

Table 58: Multivariate analysis for SP parameters recovery data: fatigue, gender and their interaction effect	144
Table 59: Multivariate analysis for SP parameters recovery data: gender effect	144
Table 60: FRP parameters processed data	145
Table 61: SP temporal parameters and intrinsic stiffness data	163
Table 62: SP magnitude parameters and effective stiffness data.....	181

CHAPTER ONE: INTRODUCTION

The overall burden of Musculoskeletal Disorders (MSDs) of the neck or cervical spine in terms of health and economics is enormous in many industrialized countries. In the United States, an annual prevalence of 30% to 50% for neck pain among the general adult population was reported by the Task Force of Bone and Joint Decade on Neck Pain (Hogg-Johnson et al. 2008). Among the working population, between 11% and 14.1% of workers were found to suffer from debilitating neck pain symptoms i.e., they are limited in their activities, because of neck pain (Côté et al. 2008a). Worldwide, neck pain has an annual prevalence of more than 50% in Finland (Mäkela et al. 1991), 34% in Britain (Palmer et al. 2001), and 21% in Netherland (Picavet and Schouten 2003). It is also estimated that about 67% of people suffer neck pain at some point in their life (Côté et al. 2004). The symptoms of neck pain often last for prolonged periods of time and reoccurrence is witnessed among 50-80% of people within the 5 years after the first occurrence (Côté et al. 2008b). The neck is more vulnerable to injuries due to the high mobility and low stability of the cervical spine compared to the other parts of the human spine (Palmer and Smedley 2007). Consequently, neck disorders are difficult to cure once they appear, and focus should therefore be on prevention measures.

MSDs of the neck or cervical spine result in longer sick leaves, constitute a substantial level of human suffering, and contribute significantly to morbidity among various working populations (Hales and Bernard 1996). Recent U.S. Bureau of Labor Statistics (BLS) data indicated that work-related neck pain requires a median of 11 days away from work to recuperate compared to 5 days for all other body parts combined (BLS 2012). In Britain and Canada neck pain has been reported to be responsible for about 15% of hospital physiotherapy and 30% of chiropractic visits (Hackett et al. 1987, Waalen et al. 1994). In Quebec, Canada statistical data indicated that around 7% of compensation claims were neck pain related (Spitzer and LeBlanc 1987). The economic impact of work related neck pain varies considerably between the working populations. A total annual cost of €2.1 billion for neck and upper extremities related MSD was reported in the Netherlands. In the United States, the exact cost of neck MSDs is unknown, but the overall annual cost of work-related MSDs is estimated to be around \$45 to \$54 billion (Bernaards et al. 2011).

The risk factors for neck musculoskeletal disorders can be broadly classified into four categories: genetic, morphological, psychosocial, and biomechanical (Kumar 2001). Although genetic and morphological factors play an important role in understanding the prevalence of MSDs, biomechanical factors greatly aid in determining effective control strategies. Therefore, an understanding of the biomechanical behavior of musculoskeletal tissues is crucial in the prevention of musculoskeletal injuries and disorders. The work-related factors that affect the biomechanical behavior of the cervical spine include static and awkward postures, repetitive upper extremity and neck movements, and forceful arm exertions (Ariens et al. 2000, Andersen et al. 2007, Cagnie et al. 2007, Palmer and Smedley 2007). Use of prolonged static and awkward head-neck postures is common among the occupational groups, such as VDT users, surgeons, sewing machine operators, and dentists (Hagberg and Wegman 1987, Côté et al. 2009, Nimbarte et al. 2013a, Nimbarte et al. 2013c). Repetitive arm and neck movement constitute a major facet of workplace tasks in several industries including fishing, food processing, wholesale and retail industry, agriculture, transportation and warehousing, assembly line, service etc. Forceful arm exertions are common among workers in industries, such as construction (Silverstein et al. 2002), healthcare (Trinkoff et al. 2003, Lipscomb et al. 2004), agriculture (Aublet-Cuvelier et al. 2006, Rosecrance et al. 2006), transportation and warehousing (Silverstein et al. 2002), and manufacturing (Chee and Rampal 2004).

A number of studies have shown that the use of static and awkward head-neck postures leads to fatigue of the neck extensors (Bjelle et al. 1981, Schüldt et al. 1986, Finsen 1999, Szeto et al. 2002). Ariens et al. (2000) reported that people who spend more than 70% of their time in static neck postures are highly susceptible to neck pain. Repetitive arm and neck exertions are also known to attribute to the fatigue of the neck muscles (Hagberg 1981, Hansson et al. 1992, Sakakibara et al. 1995, Chowdhury et al. 2012, Chowdhury et al. 2013). A few studies have also shown an active contribution by the neck muscles during forceful arm exertions leading to the fatigue (Kimura et al. 2007, Troiano et al. 2008, Nimbarte et al. 2010, Sun and Nimbarte 2011, Nimbarte et al. 2012, Nimbarte et al. 2013b, Nimbarte 2014)

In addition to the above-stated physical work-related factors, gender appears to be a common risk factor for the neck MSDs (Hogg-Johnson et al. 2008). In the United States, one year prevalence of neck pain among the general population was 40% for females compared to 29% for males (Bovim et al. 1994). Similar trend of higher prevalence of neck pain among

females than male was also reported in the studies performed among Dutch, Swedish and Japanese populations (Andersson et al. 1993, Picavet and Schouten 2003, Guo et al. 2004). Several working populations also display higher prevalence of work-related neck pain for females than males. Cagnie et al. (2007) reported an annual prevalence of 54.7% and 38.3% for females and males, respectively, among the office workers. Fernandes et al. (2011) reported higher neck MSDs among the females than males in a Brazilian plastics industry. Skov et al. (1996) reported a much higher prevalence of neck pain among the female (76%) sales workers compared to their male (54%) counterpart. Females may use different work methods compared to males in order to balance work demands. For example, Nimbarte (2014) found that females use their anterior neck muscles to a greater extent than males during lifting exertions. Use of more stressful upper extremity kinematics by females than males was reported during repetitive and/or submaximal motions in a few previous studies (O'Sullivan and Gallwey 2002, Kee 2005). Straker et al. (2011) reported more strenuous forward tilted postures for females than males during computer use. These differences in the work methods may affect the risk of fatigue induced MSDs for females compared to males.

The muscle fatigue generated by work-related exertions may affect the biomechanical stability of the cervical spine. Spinal stability is usually achieved through highly coordinated interactions of active and passive components of the neuromuscular systems (Panjabi 1992a, Granata and Gottipati 2008). A less stable spine can be both a cause and consequence of spinal pain. The most commonly used methods to assess the stability of the human spine include the flexion-relaxation phenomenon (FRP) and the response of spine to sudden perturbations (SP). The FRP is defined as the myoelectric silence of the paraspinal extensor muscles during full flexion (Floyd and Silver 1951, Meyer et al. 1993). It explains the synergistic load sharing between the muscles and viscoelastic elements (ligaments, discs, capsules, and fascia) (Andersson et al. 1996, McGill et al. 1996, Gupta 2001, Colloca and Hinrichs 2005). The SP protocol allows quantification of the muscle reflex responses necessary to maintain spinal stability (Cresswell et al. 1994, Santos et al. 2011).

Fatigue is believed to be one of the potential precursors of MSDs and despite being one of the most common consequences of the different types of work exposures, its effect on the stability of the cervical spine is currently not well understood. The main purpose of this dissertation was to quantify the post-fatigue changes in the stability of the cervical spine. In

addition, the role played by the gender in the stability of cervical spine due to the fatigue was also studied. This contribution is significant, because it will serve as the first step in a continuum of research that is expected to improve our understanding of the mechanism of pathogenesis of cervical spine disorders caused by neck muscle fatigue. The outcomes from this dissertation are expected to aid in the development of workplace intervention strategies to curtail the incidence of cervical spine MSDs.

CHAPTER TWO: LITERATURE REVIEW

2.1 Anatomy of cervical spine

Cervical spine is the top part of the spine that resides between the skull and thoracic spine. It supports the head weight, provides mobility and protects the spinal cord. It is a complex system that consists of seven vertebrae numbered C1 to C7 from top to bottom, five inter-vertebral discs, 37 separate articulations and complex system of ligaments and muscles (Palmer and Smedley 2007) (Figure 1).

Figure 1: Lateral view of the cervical vertebrae. Retrieved from Taiwan Spine center website
Center TS (2014)

Similar to the lumbar spine, the cervical spine has a backward “C” shape (lordotic curvature) which aid in equal distribution of the head weight on the spinal structures (Pal and Sherk 1988). There are two holes on the sides of each vertebra, each called transverse foramina, for the arteries to pass through to the brain. This type of arrangement coupled with the high flexibility of the cervical spine, make it less stable and more vulnerable to injury than other spinal structures (Palmer and Smedley 2007).

The C1 to C7 vertebrae provide structure, mobility, protection and stability to the cervical spine. C1 (called atlas) and C2 (called axis) have special design, which is different from

other vertebrae, to provide head rotation (Ishii et al. 2004). The atlas does not have a vertebral body, but it has a thick anterior arch and a thin posterior arch. The axis has a bony pig called the odontoid process that fits in a hole in the atlas attached by special ligaments. This configuration allows maximum head rotation from one side to another (Werne 1957, White and Panjabi 1978, Panjabi et al. 1989). Rest of the vertebra consists of vertebral body, arch, 3 foramina (2 transverse foramina and 1 vertebral foramen), and seven processes (Tortora 2005). The vertebral foramen is the hole through which the spinal cord passes.

Figure 2: Cervical spine ligaments: (A) Anterior longitudinal ligament, (B) Posterior longitudinal ligament and (C) Ligaments of the cervical spine. Adapted from Gilroy et al. (2008)

The ligaments are passive tissues that connect bones around a joint, provide passive support and aid in maintaining structural stability. Main ligaments that stabilize the cervical spine include anterior longitudinal ligament and posterior longitudinal ligament (Figure 2). The anterior longitudinal ligament (Figure 2A) extends anteriorly along the vertebral bodies from C1 to sacrum S1. The posterior longitudinal ligament (Figure 2B) extends posteriorly along the surface of the vertebral bodies from C1 to S1. Other cervical spine ligaments include nuchal ligament, supraspinal ligament, and interspinous ligaments (Figure 2C) (Gray and Carter 2008).

Each of the cervical vertebral bones articulates with the bone above at the superior articular facet and also articulates with the bone below it at the inferior articular facets. Despite lacking a vertebral body, C1 has two additional articular surfaces on the superior aspect of the bone. These surfaces articulate with the base of the skull allowing the motion in the sagittal plane (Tortora, 2005). On the other hand, the inferior articular facets articulate with C2 allowing the motion in the transverse plane.

Between two vertebrae (C2 through C7) there is a facet joint called zygapophyseal that resides between the inferior articular facets of one vertebra and the superior facets of the next vertebra. Unlike C1 and C2, there is no direct contact between the bodies of the vertebrae as an intervertebral disc separates them. The vertebral discs consist of an outer fibrous ring (annulus fibrosus) and an inner soft center (nucleus pulposus). Their function is to support the spine, facilitate its movement and absorb any vertical shock applied to the spine (Tortora, 2005).

The main cervical spine muscles are sternocleidomastoid (Figure 3), upper trapezius (Figure 3), and cervical paraspinal muscles (Figure 4). The sternocleidomastoid muscle arises from the clavicle and sternum and inserts into the mastoid process of the temporal bone (Tortora 2005). The bilateral contraction of the sternocleidomastoid muscle causes cervical spine flexion and head extension (Tillmann and Elbermani 2007). The unilateral contraction of the sternocleidomastoid muscle causes ipsilateral flexion (flex to the opposite side) and contralateral rotation of the head (Tortora 2005). The extension of the cervical spine produced by the bilateral contraction of upper trapezius and other cervical paraspinal muscles. The upper trapezius muscle originates at the occipital bone and inserts in the posterior part of the clavicle and the spine of scapula (shoulder blade). The cervical paraspinal muscles extend from several locations all over the cervical spine and consist of erector spinae muscles (splenius

capitis, splenius cervicis, semispinalis capitis, longissimus capitis, and ilicostalis cervicis), rectus capitis major and minor, levator scapulae, and obliquus capitis muscles (Figure 4). Upon the unilateral contraction of the cervical paraspinal muscles muscles, ipsilateral flexion and rotation of the head is expected (Tortora 2005, Tillmann and Elbermani 2007) .

Figure 3: The sternocleidomastoid (a) and trapezius (b) muscles. Adapted from Tortora (2005)

Figure 4: Cervical paraspinal muscle group. Adapted from Gilroy et al. (Gilroy et al. 2008)

2.2 Flexion-Relaxation Phenomenon

In 1911, Fick proposed a theory that during full flexion of the vertebral column, the lumbar spine will relax without any activity and will be supported by ligaments (Fick 1911). Experimentally, flexion-relaxation phenomenon (FRP) was first recognized in the lumbar spine by Floyd and Silver in 1951 (Floyd and Silver 1951). They referred to it as an inhibition of the paraspinal muscles (Floyd and Silver 1951, Floyd and Silver 1955). FRP was defined as the phenomenon of myoelectric silence of paraspinal musculature during full flexion. It is the result of load or moment sharing between the active structure (muscles) and the passive structures (i.e. ligaments, fascia, and bones) (Schultz et al. 1985, McGill and Kippers 1994, Gupta 2001, Colloca and Hinrichs 2005). As the flexion angle of the trunk increases, the activity of posterior muscles increases to compensate for the increase in the gravitational moment. Meanwhile, the passive tissues (i.e. ligaments along the dorsal side of the spinal column) are stretched continuously and placed in tension. Increased activation of deep muscles (lateral erector spinae and quadratus lumborum muscles) is also observed with the increase in the flexion angle (Andersson et al. 1996). As flexion progresses, a continuous tradeoff in the force generation between active muscles and passive tissues is observed until a point is reached after which the muscle activity is almost zero and passive tissues carry the entire load (Schultz et al. 1985, Shirado et al. 1995, Mathieu and Fortin 2000, Sarti et al. 2001).

2.2.1 Lumbar spine FRP

Since 1951, extensive experimental investigations were performed on the lumbar spine FRP with a primary focus on (i) identifying consistency and predictability of this phenomenon, (ii) quantifying effect of various external factors and (iii) differentiating healthy people from people with low back pain. In the following sections the existing lumbar spine FRP literature is summarized.

2.2.1.1 Effect of load and speed

Floyd and Silver (1955) investigated the effect of lifting tasks performed using a load of 12.7 kg on the lumbar spine FRP. Results showed that the lifting tasks affected the FRP by showing the onset angles earlier and delaying the offset angles. Tousaint et al. (1995) performed similar type of study and used a load of 15.3 kg. In the fully flexed posture a decrease in the muscle activity was observed. The authors also reported that the lumbar range of motion

increased after the completion of lifting tasks suggesting more contribution by the passive structures to stabilize the spine.

Lariviere et al. (2000) studied the effect of load on FRP during flexion extension and lateral bending tasks in normal and symptomatic people. A weight of 12 kg was used. The participants (n = 48 males, 15 with symptoms of low back pain) performed trunk flexion in the sagittal and frontal planes with or without the load. Results indicated that a 12 kg load was not sufficient to differentiate between healthy people and symptomatic people in terms of FRP. However, the authors reported that the people with low back pain increased their thoracic flexion to compensate the loss of lumbar flexion.

Gupta (2001) evaluated the effect of three load conditions (no load, 10 kg in the front and 10 kg on the back tied around iliac crest) on the FRP in erector spinae muscles. The pelvic-hip posterior movement was controlled in this study by restraining the buttocks of participants against a wall (n = 25). The FRP was observed in all subjects and with the addition of load, an early onset and delayed offset was observed. Gupta concluded that the FRP is the result of passive equilibrium between the torques induced by gravitational forces and stretched passive structure. Sarti et al. (2001) investigated the effect of load (10 kg) and speed (fast: 3 second and slow: 8 seconds) on lumbar FRP (n = 22). The data was represented as a function of relative time of spine motion. In general, flexion requires more time than extension. Load had no significant effect on the spine motion time. Speed significantly increased the trunk flexion time and significantly reduced the trunk extension time. Moreover, increase in the speed delayed the appearance of silence period in the flexion phase. In another study on the effect of velocity on lumbar stability, Bazrgari et al. (2008) indicated that full or partial FRP appeared only at low velocities.

2.2.1.2 Effect of posture

Callaghan and Dunk (2002) studied FRP in three postures: upright standing, upright sitting and slumped sitting (n = 22, 11 females and 11 males). In general, smaller onset angles were observed during sitting postures compared to standing postures. In nearly 80% of the participants, the FRP was observed in all the studied muscles (lumbar and thoracic) in the standing position. In the sitting position, FRP was observed for thoracic muscles and the lumbar muscles showed constant activation. In the slumped sitting, increased FRP for the thoracic

muscles was observed. O'Sullivan et al. (2006) studied the lumbar FRP during a motion from upright sitting to slumped sitting posture (n = 24, 14 men and 10 women). Participants moved from upright posture by relaxing their thoracolumbar spine and rotating their pelvis into posterior tilt. For the lumbar region the FRP was found to be consistently present when moving from upright to slumped sitting. In the thoracic region the electromyography (EMG) activity was highly inconsistent and the FRP was only observed in 11 participants.

Olson et al. (2006) explored the effect of gravity on the lumbar flexion-relaxation phenomenon (n = 13). Two positions were studied: standing upright and supine. Participants performed five cycles of flexion-relaxation procedures during each studied posture. Results showed that muscles recruitment for the FRP depends on the gravitational orientation. Changing the position from standing into supine caused the FRP to disappear in the lumbar paraspinal muscles and to show up in the abdominal muscles during flexion.

2.2.1.3 Effect of cyclic loading

Dickey et al. (2003) studied the effect of repetition on FRP (n = 30; 15 males). Participants performed a sequence of 100 flexion-extension trials. The flexion-relaxation procedure was performed by flexing the back in 4.5 sec, maintaining the full flexion for 2 sec and extending to the neutral position in 4.5 sec. The sequence of the 100 flexion-extension was divided into: the first 10 trials without load, the second 10 trials with load in hands, trials from 81-90 with load in hands, trials 91-100 without load and the middle sixty trials with 50% of the load. Male participants had a load of 10 kg while females had a load of 5 kg. Only the first and last 20 repetitions were included in the statistical analysis. Results showed that 23 out of the 30 participants showed FRP after the repetitions with no gender differences. Authors reported that flexion-relaxation occurred at an angle of 92.7% of maximum flexion and was not affected by the repetition as well as the load. However, load and repetition-load interaction had significant effects on the maximum flexion angles. The maximum flexion angles increased with load and repetition-load interaction. This increase is explained by the creep formation in the passive tissues due to repetitive flexion. Muscle activity in both the lumbar and thoracic regions increased with repeated flexion. Authors concluded that flexion repetition will induce creep in the passive tissues and consequently modulate the flexion-relaxation behavior.

2.2.1.4 Creep Effect

Solomonow et al. (2003a) investigated the FRP differences between males ($n = 24$) and females ($n = 25$). EMG from erector spinae muscles and kinematic data were collected during the performance of the flexion-extension before and after 10 minutes of static flexion. Static flexion procedure was performed by instructing the participant to sit on a physical therapy mat with a full lumbar flexion posture. A hemi-cylindrical foam bolster was positioned under the hips to posteriorly flex the pelvis (knees flexion was allowed). This procedure was used to induce creep in the passive tissues. Flexion-relaxation procedure was repeated three times before and after the static flexion. The participants stood upright for 3 sec, fully flexed the lumbar spine within 2-3 sec, maintained this position for 3-4 sec and then extended into the upright position within 2-3 sec. Regardless of gender, results showed higher muscles activation and larger flexion angles after 10 minutes of static flexion indicating creep development in the viscoelastic tissues. Females showed more change in the FRP than males due to the higher creep development. Results also indicated that creep formation in the passive tissues caused the silent period to decrease by appearing later and ceasing earlier. Two other studies by Shin et al. (2009) also reported a decrease in the silent period due to the formation of creep in the passive tissues. In these studies a combination of isometric and isokinetic trunk exertions were used by the authors to study the effect of creep and passive tissue deformation on the FRP parameters.

2.2.1.5 Effect of fatigue

Olson et al. (2004) investigated the effect of cyclic lumbar flexion on the FRP. Twelve male participants continuously repeated flexion extension cycles for 9 minutes. Each cycle consisted of anterior flexion for 5 sec from erect posture to full flexion, followed by another 5 seconds of extension. Results showed that cyclic lumbar flexion significantly altered lumbar FRP by expanding the silent period. The expansion in the silent period was evident by the early onset and delayed offset of the silent period. Accordingly, the EMG activity in the lumbar muscles had significantly increased to compensate for the development of fatigue and spasms in the deep muscles.

Descarreaux et al. (2008) investigated fatigue as a possible modulator of the lumbar muscle FRP ($n = 20$). Fatigue was induced using the Sorenson Protocol. Four cases were studied: no fatigue/no load, no fatigue/load, fatigue/no load, and fatigue/load. A load of 12 kg

was used in the loading conditions. The load (barbell) was held with elbows flexed at 90° angle. The flexion-extension procedure was repeated 3 times for all conditions. The participants (n = 20) fully flexed their trunk during 5 sec, maintained the full flexion for 3 sec and extended their trunk back to the neutral posture within 5 sec. The EMG and Kinematic data were collected before and after the fatigue/load protocol. Results indicated that fatigue has shifted the FRP by showing onset angles earlier and delaying offset angles regardless of load condition. Load significantly increased onset angles and had no significant effect on the cessation angles.

Descarreaux et al. (2010) also studied the effect of fatigue on the flexion-relaxation in the hip extensors and lumbar spine erector spinae muscles. The experimental procedure was similar to the experimental procedure used in their 2008 study (2 fatigue levels by 2 load conditions). The fatigue was induced in the hip and trunk extensor muscles by sustained isometric contractions. The participants exerted isometric forces at 60% of their maximum voluntary contraction (MVC) by pushing their feet against a board equipped with a dynamometer plate. Participants were encouraged to maintain this same level of exertions as long as possible. The protocol was stopped when the participants failed twice to maintain the force level between 55-65% MVC. The results were similar to their 2008 study. Also, the authors indicated that fatigue decreased the lumbar spine extensor spinae muscle involvement in the FRP compared to the hip extensors. In summary, muscular fatigue of the lumbar spine erector spinae and hip extensor muscles was reported to alter the lumbopelvic dynamics.

2.2.1.6 Symptomatic and a symptomatic people

Neblett et al. (2003) quantified the effect of rehabilitation program on the FRP using 12 normal and 34 symptomatic participants. The participants performed the flexion-relaxation in a neutral standing position. The flexion-relaxation was observed in all normal participants and was found to be absent in all symptomatic participants before the rehabilitation program. After completing the rehab program, 94% of symptomatic participants showed the flexion-relaxation. The authors concluded that FRP can be used to assess the effectiveness of rehabilitation and training programs. Similar findings were also reported by Mayer et al. (2009) and Neblett et al. (2010). In most of these studies a cutoff point of 3.5 μ V of EMG during the silence period was used to determine the existence of the FRP.

Dankaerts et al. (2006) compared active muscles patterns between non-specific chronic low back pain group and control group (pain free). The total sample size was 67 (control = 34 and non-specific chronic low back pain = 33). The EMG data was collected from ten superficial trunk muscles during two sitting positions (usual and slumped). Usual setting is the normal adopted posture during unsupported sitting. Slumped sitting is the sitting while trying to fully relax the spine. The flexion relaxation ratio was found to be significantly lower for the non-specific chronic low back pain group (FRR = 2.7) than control group (FRR = 4.6).

2.2.1.7 General

Raftopoulos et al. (1988) investigated the FRP during lateral bending exertions (n = 9 males). The study participants performed lateral bending tasks with and without load (5 kg) to the right and the left side. In general, increased EMG activity was observed for the low back muscles with the addition of load. The FRP was observed in the erector spinae muscle, but was found to be absent in the lateral oblique abdominal muscles.

McGorry et al. (2001) studied the effect of posture and speed on FRP (n = 6 males). Three postures: upright standing, restricted standing, and sitting, and two speeds: slow and fast were tested. In the low speed, participants were asked to flex their trunk in 3 sec, maintain this position for 1 sec and extend in 3 sec. In the fast speed, participants flexed their trunk in 2 sec, maintained the full flexion for 1 sec and extended to the upright position in 2 sec. Muscle recruitment was reported to be independent of speed and dependent on posture. The FRP appeared in all lumbar regions and was found to be inconsistent in the hip region. The measured data was consistent over the 6 weeks period (bi-weekly test).

Alschuler et al. (2009) studied the association between flexion-relaxation and low back pain clinical features (pain intensity, perceived disability, and pain-related fear). Participants' musculoskeletal status was evaluated by conducting a manual medicine screening. The screening was conducted by a physical therapist. The EMG data at the L3 and L5 levels and the range of motion data was collected from seventy six participants while performing the flexion-relaxation procedure. Participants stood upright for 2 sec, flexed their trunk within a count of 2, maintained the full flexion for 2 sec, and extended their back in 2 sec. FRP was represented by two ratios: (i) dividing the max surface EMG during Flexion by the average surface EMG during maximum voluntary flexion and (ii) by dividing the max surface EMG during extension

by the average surface EMG during maximum voluntary flexion. Both ratios were found to be correlated with the range of motion ($r = 0.51$, $P < 0.001$), 2 measures of perceived disability ($r = -0.31$, $P < 0.01$), pain-related fear ($r = -0.45$, $P < 0.001$), and elicitation of pain during straight leg raise ($r = 0.30$, $P < 0.05$). Authors suggested that these ratios can be used to evaluate interventions to treat patients with low back pain.

Ning et al. (2011) investigated the effect of asymmetry on the FRP ($n = 12$). Three trunk asymmetry postures were tested: 0° , 10° , and 30° from the mid-sagittal plane. The EMG data from the paraspinal muscles at the L4 and L3 levels were reordered in addition to the lumbar spine kinematics data during the flexion-extension procedure. The participants' pelvis was restrained in a special made frame (asymmetric reference frame) while performing the flexion-extensions. Participants were instructed to fully flex their trunk within 7 sec, maintain the full flexion for 5 sec and then extend back to the neutral posture within 7 sec. This procedure was performed 5 times for each trunk asymmetry posture. Results showed that range of motion decreased as the trunk asymmetry increased. FRP for ipsilateral muscles vanished gradually as the trunk asymmetry increased and did not show at 30° trunk asymmetry. Ten percent reduction in the maximum lumbar flexion was detected when asymmetry increased from 0° to 30° .

Shan et al. (2012) studied the effect of spinal shrinkage on the erector spinae FRP ($n = 12$, all males). Spine shrinkage was developed by placing load (20% of body weight) on shoulders using barbells for 10 minutes. Shrinkage was measured using stadiometer. FRP was tested before and after the shrinkage development. The spine suffered a 5.9 mm shrinkage that significantly affected the FRP parameters. The shrinkage caused higher muscles activity and shifted the onset angle to appear later and the offset angle to show earlier (silent period decreased). The authors discussed that the shrinkage effect is similar to the cyclic loading effect on the FRP.

2.2.1.8 Muscles recruitment patterns in lumbar spine FRP

Pauly (1966) studied muscles activities using EMG of the back (especially deep muscles) and neck during several movement and exercises. He reported that muscles recruitment patterns are complex and depend on posture and task performed. He also reported that FRP was observed in the lumbar region during the “Bend and Stretch” exercise, but it was not observed in the cervical region.

Andersson et al. (1996) investigated the activity of different erector spinae muscles during the FRP and other motor tasks by collecting EMG data. Quadratus lumborum, deep lateral and superficial medial lumbar erector spinae, psoas, and iliocostalis muscles were studied in this experiment during standing, sitting and supine positions. The results showed spine stability is based on a complex muscle recruitment process which is a function of task performed. For example, during the neutral standing position quadratus lumborum, deep lateral erector spinae and superficial erector spinae muscles were all silent. During full flexion the superficial erector spinae was active while the other two were silent, and at the relaxation phase (achieving FRP) the superficial erector spinae muscle was silent and the two others were active.

2.2.2 Cervical spine FRP

A limited literature is available on the FRP in the cervical spine. It started when Meyer et al. (1993) investigated this phenomenon in the cervical spine using surface EMG in the seated orthograde position. Ten participants, seated upright, were instructed to flex their heads slowly till the chin reached the upper chest, maintained this position until they were instructed to return to the initial position. The visual analysis of the surface EMG data indicated the existence of FRP in the cervical spine in all participants.

2.2.2.1 Effect of load and speed

The effect of load (load, no load, and counterweight load) and speed (low speed: 5 second flexion, and high speed: 2 seconds) on the cervical FRP was investigated by Pialasse et al. (2010). Load effect was found to be statistically significant on both FRP kinematics and muscle activity parameters. Speed and load-speed interaction effects were identified in the kinematics data. In electromyography data, speed and load-speed interaction were only statistically significant at the extension phase specifically at higher loads and higher speed.

Lee et al. (2011a) studied the effect of backpack (load) on the cervical FRP (n = 14, all males). The flexion-extension procedure was performed at three different loading conditions: no load, 10% and 20% of the body mass. The flexion-extension ratio was calculated by dividing the maximum EMG data during the extension phase by the average EMG data in the relaxation phase. Participants were instructed to flex their head within 5 sec, maintain the full flexion for 5 sec and extend the head back to the neutral posture within 5 sec. The EMG data was collected at the C4 level. The results indicated a decrease in the flexion-extension ratio as the load

increased. Backpack was reported as a risk factor for neck pain. In general, the authors indicated that the FRP can be used to assess neck pain and associated interventions.

2.2.2.2 Effect of posture

Burnett et al. (2007) tested the appearance of the cervical FRP in lumb-pelvic sitting position by trying 6 different criterion used in literature to define the FRP (n = 20). Neck muscle EMG data and kinematic data were collected from 20 healthy participants (10 males) while performing head-neck flexion-extension. Participants while seated flexed their head within 5 sec, maintained the full flexed head posture for 5 sec, and returned to the upright posture in 5 sec. The procedure was repeated 4 times. The following 6 criteria were used to check the presence and absence of the FRP:

Criteria 1: visual inspection based on reduced muscle activity in phase 3 (relaxation) compared to Phase 1 (starting neutral upright posture).

Criteria 2: statistical analysis to determine significance of criteria 1.

Criteria 3: phase 3 EMG activity $\leq 3\%$ of MVIC.

Criteria 4: phase 3 EMG $\geq 1\%$ of MVIC less than Phase 1.

Criteria 5: phase 3 EMG $\leq 10\%$ of peak EMG during Phase 4 (Re-extension).

Criteria 6: ratio of Phase 3 to Phase 2 (Flexion) < 1 .

Results indicated that the presence of cervical FRP varies depending on the criterion being used.

Piallasse et al. (2009) also studied the effect of sitting postures on the cervical spine FRP. Two sitting positions were studied; neutral posture and 45° forward flexion. EMG data from the cervical paraspinal and trapezius muscles were collected from 19 healthy participants. Participants were asked to flex their head in 4 sec, maintain the full flexion for 3 sec, and then extend their head back to the upright posture. Results reported a significant difference between the SEMG amplitude between the two positions, but no significance difference in regard to kinematic parameter (onset and offset angles). The FRP was evident unilaterally in 90.5% (79% bilateral) of the inclined position, and 84.2% unilaterally (67.4% bilaterally) of the neutral posture.

2.2.2.3 General

Airaksinen et al. (2005) compared the cervical FRP between patients with neck pain and pain free controls. Flexion-extension was performed while participants were seated in a chair with back and head in the neutral posture. The EMG data was collected at the C4-C5 level. Results showed that the FRP was seen clearly in healthy group and was absent in the symptomatic group.

Murphy et al. (2010) studied the FRP for chronic neck pain patients (n = 14) and healthy control (n = 11) at baseline and after 4 weeks. The participants performed seated head flexion-extension: flexion in 3 sec, maintained the full flexion for 3 sec and extended their head back to the neutral posture within 3 sec. The EMG data was collected at the C4 level. The results for the FRR showed high reliability. The intraclass correlation coefficient (ICC) was found to be 0.89 for the combined data from all participants. The FRP was found to be consistent for both groups at the baseline and after 4 weeks. The flexion relation ratio was found to be higher for the healthy people (around 4) than people with chronic neck pain (around 2).

Yoo et al. (2011) studied the relationship between the cervical flexion relaxation ratio and the range of motion among healthy computer workers (n = 20). The EMG data from the cervical erector spinae muscle and head kinematic were collected during the flexion-extension procedure. Participants were asked to flex their head in 5 sec, maintain the full flexion for another 5 sec, and extend back their head to the neutral posture within 5 sec. The relationship between the flexion relaxation ratio and the range of motion was quantified by calculating the Pearson correlation coefficients. The flexion relation ratio was calculated by dividing the maximal EMG during the extension phase by the average activation during the relaxation phase. Statistically, the range of motion and flexion relaxation ratio data was found to be positively correlated in flexion, lateral flexion, and right lateral rotation, but not in the extension and right rotation.

Maroufi et al. (2012) compared the cervical FRP in asymptomatic participants (n = 21 all females) with chronic neck pain participants (n = 22, all females). The flexion relaxation ratio was calculated by dividing the peak of EMG activity during the extension phase by the peak of EMG activity during the relaxation phase. Participants while seated in a chair with hips and knees at 90° angle performed the neck-head flexion-extension procedure. They maintained

the neutral posture for 4 sec, flexed their head within 4 sec, maintained the full flexion for 4 sec and extended their head back within 4 sec. The EMG data at the C4 level and the head kinematics were collected during the flexion-extension procedure. There was a significant difference in the appearance of FRP between the healthy (86% showed the FRP) and symptomatic participants (36% showed the FRP). The flexion relaxation ratio was 4.88 ± 1.4 and 2.22 ± 0.7 for asymptomatic and symptomatic participants, respectively.

2.3 Sudden Perturbation

Expected or unexpected (sudden) perturbations are commonly used to investigate spine/joint stability. Perturbations forces applied to the spine/joint trigger the Central Nerve System (CNS) response to restore the spine or joint postural equilibrium (Simon 1994). Spinal stability can be achieved in two ways: (1) voluntary strategies with no delay through feed-forward contraction of pre-activated spinal muscles, (Hodges and Richardson 1997b), (2) through afferent feedback caused by response to perturbation that creates a delayed muscular co-contraction (force) and stiffness (Cresswell et al. 1994). Simon stated that a perturbation force applied to the lumbar spine will result in transient tissue strain and excitation of large mechanoreceptors (i.e., Golgi and Pacinin fibers) in the ligaments and muscle spindle sensors (type I and type II afferent). This initiates a ligmento-muscular reflex activity to stabilize the spine (Simon 1994). The ligament-muscular reflex activity in human has been studied for spine, knee, ankle joints, elbow, and shoulder using the perturbation technique. Some of these studies are reviewed in the following sections:

2.3.1 Muscle reflex in lumbar spine

In general, sudden (unexpected) perturbation was reported to increase muscle activity and show higher displacement compared with expected perturbations (Marras et al. 1987, Lavender et al. 1993, Cresswell et al. 1994, Thomas et al. 1998). Marras et al. (1987) was one of the first researchers to examine expected and unexpected load perturbations on the spine. The participants ($n = 12$ male) were instructed to lift a box at a specific height while several loads between 2.27 and 9.07 kg were dropped into the box. This was done under expected and unexpected (no visual or auditory feedback) conditions. It was found that peak muscle forces were significantly higher in the unexpected condition than the expected condition. In addition to studying the trunk muscle activity, Cresswell et al. (1994) examined the intra-abdominal

pressure under unexpected and expected perturbations conditions. Loads were added to a harness mounted on the shoulders. The increase in load caused an increase in both the muscle pre-activation and the intra-abdominal pressure. Consequently, the spine rigidity was increased and the stability was improved. Thomas et al. (1998) investigated the effect of expected/unexpected loads under symmetric/asymmetric conditions. The EMG activity of eight torso muscles, kinematic and kinetic data was collected to calculate peak latency and stiffness. In the expected condition the peak latencies of the posterior torso muscles always preceded the peak latencies of the anterior ones. However, no significant differences were found between the peak latencies for the posterior and anterior trunk muscles in the unexpected condition except for the logissimus thoracic muscle. The result suggests that trunk muscles initiate preparatory stabilizing strategies to improve spinal stability following the loading conditions. In a study performed by Van der Burg (2000) the participants laterally lifted a crate with known and unknown weights. The onset of the bending moment started later in the expected condition compared to the unexpected (sudden) condition. Also, the muscle stiffness was lower for the unexpected condition compared to the expected condition. The results indicated that unexpected load is a risk factor of spine instability and injury. Brown et al. (2003) also reported similar finding when compared expected and unexpected perturbations.

Santos et al. (2011) conducted a reliability study for the calculation of the back muscle reflex response using sudden perturbations. Fifteen male participants performed the test at two different days doing 5 repetitions using two load conditions (no pre-load and with preload). During the sudden perturbations, EMG activity and trunk kinematics data were recorded. Variances and reliability of measures were computed using the generalizability theory. Results showed a poor to moderate reliability (ICC between 0.0 and 0.62). Reliability was improved by increasing the number of trials and averaging the EMG data of both sides. Authors concluded that the reflex response of the back is variable and large number of data points is required to enhance the reliability.

2.3.1.1 Load, preload effect

Chiang (1997) , Chiang and Potvin (2001), and Krajcarski et al. (1999) investigated the lumbar spine muscles response to sudden perturbation under different preload and added load magnitude. In response to the sudden perturbation, all studies showed a higher muscle activity and reduction in the angular displacement due to the increase in trunk muscles stiffness to

maintain spine stability. Results also showed that low pre-load and high added load resulted in higher instability and peak moment at L4/L5 compared to the high pre-load and low added load condition.

Cholewicki et al. (2000) investigated the trunk stability using sudden loading in the trunk flexion, extension and lateral bending planes. Horizontal loads of 0, 10 and 20% of subjects' body weight and vertical loads of 0, 20, and 40% of the body weight were used. Twelve healthy subjects (6 females) were exposed to sudden perturbation by releasing the vertical and horizontal loads. Effective trunk stiffness was calculated by using trunk kinematics and force data while spinal stability was calculated by combining the EMG data with a biomechanical model. Results showed an increase in the spinal stability and muscle stiffness in response to the increase in the external trunk loading independent of the motion planes and the loading directions.

Gardner-Morse and Stokes (2001) studied the effect of steady-state preload and horizontal loading directions on trunk stiffness. Fourteen participants underwent sudden perturbation initiated by two loads (7.5 and 15% of their maximum extension effort) at two different pre-load conditions (20% or 40% of their maximum extension effort). The directions of loading were 0, 45, 90, 135 and 180 degrees to the forward direction. Kinetics and kinematics data were recorded to calculate trunk stiffness by fitting the experimental data to a second-order differential equation of the trunk dynamic behavior. Results showed that stiffness significantly increased with the increase of preload. Also, a moderate, but significant variability was observed in the stiffness due to loading direction. The increase of stiffness was the result of increase in the muscle activity to stabilize the spine.

2.3.1.2 Posture effect

Moorhouse and Granata (2005) examined the effect of trunk flexion on the reflex response using sudden perturbations. Subjects ($n = 21$, 11 females) underwent isotonic flexion preloads of 100, 135 and 170 N at T10 level using servomotor. A load of 730 N was used to impose sudden perturbations on the trunk. Trunk Kinematics and kinetics were measured to calculate trunk dynamics represented by muscle stiffness. Stiffness was calculated using a nonparametric impulse response function (IRF). This is the transfer function of the association between pseudorandom force input disturbances to the displacement output using time-domain

deconvolution analyses. The IRF data showed that the trunk act as an underdamped second order system due to the effect of sudden perturbations. The accuracy of the model was computed by comparing the calculated displacement with the measured (observed) one. The fit accuracy of the model was $96 \pm 4.3\%$. Stiffness increased as the preload increased.

Granata et al. (2005) investigated the influence of static flexion-relaxation on the trunk reflex muscle behavior using sudden perturbation. Subjects ($n = 18$) performed a 15 min of lumbar static flexion by sitting on the floor with lumbar fully flexed and legs extended to ensure the occurrence of the lumbar flexion-relaxation. Muscle recruitment, reflex gain and kinetics and kinematics data was collected before and immediately after the static flexion. Reflex gain was estimated as the peak value of the impulse response function (IRF) curve. The findings showed an increase in the reflex gains after static flexion. Reflex gain was statistically affected by flexion-relaxation, gender, preload, and gender-preload interaction. Females exhibited higher reflex gain than males. Data indicates that work activities that require static trunk flexion may modulate the reflex muscle responses and consequently contribute to back MSDs.

Lee et al. (2006) investigated the effect of muscle co-contraction on the trunk dynamics including stiffness, damping and mass during extension exertions using sudden perturbation. The EMG data was collected from the left and right rectus abdominus, lumbar paraspinal, internal oblique, and external oblique. In addition to the EMG data, trunk kinematics and kinetics data were collected during the sudden perturbations. A servomotor was used to supply two preloads; 15% (low co-contraction) and 30% (high co-contraction) of the participants' maximum voluntary extension. Participants were instructed to resist the effect of preload to maintain the upright standing posture. Perturbations of ± 70 N were used in this study. Stiffness was calculated using a nonparametric impulse response function (IRF). Results showed an increase of 38% in the trunk stiffness from the low to the high co-contraction (preload). The EMG activity also increased indicating that the muscle recruitment patterns were different between the two co-contractions conditions. Accordingly, co-contraction triggered by the preloading condition attribute to spine stability by increasing muscle stiffness.

Herrmann et al. (2006) and Dupeyron et al. (2010) studied the effect of fatigue on trunk muscle reflex response using sudden perturbation. Fatigue was induced by asking the participants to do multiple sets of back extensions and intermittent isometric maximum

voluntary contractions (MVC). Trunk muscle EMG activity and force data were collected to calculate the reflex delay and reflex amplitude. Reflex delay is the time difference between the onset of the perturbation and the onset of the EMG activity. Onset was determined when the value exceeded the mean by 2 standard deviations. Reflex amplitude is the EMG difference between the peak EMG and average EMG activity prior to perturbation. Results of both studies did not show any effect of fatigue on the reflex delay. However, both studies reported a significant increase in the reflex amplitude due to fatigue effect. Authors explained the increase in the reflex amplitude as an attempt to compensate for the losses in muscle force capacity.

Granata and Rogers (2007) investigated the effect of torso flexion on the reflex response using sudden perturbations. Sixteen participants performed voluntary isometric trunk extensions at four different trunk angles: 0, 30, 60, 90 degrees with respect to the lower limbs. A servomotor was used to impose the sudden load to the trunk at T8 level before and after torso flexion. The servomotor produced loads of 15% and 30% of the participants' isometric maximum voluntary exertions. Trunk EMG activity, trunk kinematics and kinetics data were collected to calculate the reflex gain and muscle stiffness. Reflex gain was calculated using the IRF based on the association between force and EMG. Stiffness was calculated using the IRF function based on the association between force and displacement. Results showed a significant increase in stiffness with the increase in the flexion angle and exertion level. Reflex gain decreased significantly with the increase in the flexion angle. However, the reflex gain increased with increase in the exertion level.

Moorhouse and Granata (2007) examined the role of reflex response in spinal stability using sudden perturbations. Eleven healthy participants were exposed to pseudorandom position perturbations to the torso to record the kinetics and kinematics from the trunk. Participants were instructed to exert pre-specified levels of 20%, 35% and 50% of their maximum voluntary exertion. During these exertions, participants were instructed to relax their trunk flexor muscles to minimize antagonistic co-contraction. After that participants underwent sudden position perturbations at T10 level. Active muscle stiffness has two components; the intrinsic stiffness and the reflex stiffness. Intrinsic stiffness is the result from the mechanical characteristics (viscoelasticity) of the joint, passive tissue, and active muscle fibers. Reflex component is triggered by sensory responses due to changes in muscle activation levels. Reflex stiffness supplies restorative forces similar to intrinsic stiffness but are time delayed. The latency is due

to response delay of the reflex loop. Stiffness was computed using a nonparametric impulse response function (IRF). In more than 60% of trials, results showed the response of the proportional intrinsic was less than zero. This indicated that intrinsic stiffness by itself was not capable of stabilizing the spine. On the other hand, reflexes were found to be responsible for 42% of the total stabilizing stiffness. This indicates that both intrinsic and reflex stiffness are critical components of spine stability.

2.2.1.3 Fatigue and creep effect

Grondin and Potvin (2009) studied the effect of fatigue and loading time on trunk muscle responses during sudden hand loading. Female subjects ($n = 15$) responded to sudden hand loads at known and unknown times. These conditions were tested while resting, with back muscle fatigue and with combination of abdominal and back muscle fatigue. Pre-activation was not different between the two conditions, while muscles activity and forces were higher in the unexpected condition. Due to the fatigue effect an increase in co-contraction was observed in the two conditions to preserve spinal stability. Authors also observed an increased level of activity both muscle groups (opposing) when only one muscle group was fatigued. This is an indication of the changes in the recruitment patterns among muscle groups to compensate for the loss in force and maintain the spinal stability.

Sanchez-Zuriaga et al. (2010) investigated the influence of creep and fatigue on the activation response of trunk muscles (at T10 and L3 levels). Creep was induced by sitting flexed for 1 hour, while fatigue was induced using the Sorenson protocol. The two variables were tested at two different days using 15 participants (8 females and 7 males). Sudden perturbations were initiated before and after each intervention to collect the EMG activity of the trunk muscles and trunk kinematics. Results showed a significant effect of creep on the reflex latency (increased from 60 ± 12 msec to 96 ± 26 msec), but did not affect the EMG peak amplitude or time to peak. Fatigue had no effect on any of these parameters. Consequently authors concluded that prolonged static flexion due to creep formation in passive tissue is a risk factor for neuromuscular impairment and low back pain.

2.2.1.4 Gender effect

Miller et al. (2010) used sudden perturbation to investigate the effect of gender on the paraspinal reflex delay/latencies. Twenty participants (10 males and 10 females) were exposed

to repeated trunk flexion perturbations. Participants were exposed to 5 different levels of perturbations (impulses) by adjusting the location of the weight on the pendulum; 3.97, 5.96, 7.67, 9.00 and 10.21 N.s. The procedure was repeated 5 times for each level of the perturbations. The activity of the trunk muscle, trunk kinetics and kinematics data were recorded to calculate the reflex delay and maximum trunk flexion velocity. Results showed that reflexes occurred at 94% of the perturbations. The findings also showed that females exhibit shorter reflex latencies (16.4%) than males. The maximum trunk flexion increased with the increase in the level of perturbations in both genders. However, females were 35.3% faster than males in their response when exposed to the same level of perturbations.

2.2.1.5 Muscle reflex in lumbar spine in people with back pain

It has been suggested that motor control impairment of the trunk is one of the mechanisms correlated to low back pain (Panjabi 1992a, Panjabi 1992b, Cholewicki and McGill 1996). Accordingly, the response to expected or unexpected perturbation might be different between people with low back pain and healthy people.

Radebold et al. (2000) investigated the response latency in people with chronic low back pain (CLBP) using sudden perturbations. Thirty four participants (normal = 17, people with low back pain = 17) were exposed to trunk loading at T9 using an electromagnetic system. EMG activity of 12 major muscles was recorded during the sudden perturbations to calculate the reflex latencies. Results showed that people with CLBP had longer reaction time (latency = 83 msec) to perturbations than normal people (latency = 70 msec). Also muscle recruitment patterns showed high variability among people with CLBP compared to healthy ones. Healthy people responded by activating almost all of their antagonist muscles and shut off most of their agonistic muscle. However, people with CLBP tended to co-contract both their agonists and antagonists muscle in response to perturbations.

In a similar type of study, Cholewicki et al. (2002) studied the back muscle reflex response to sudden perturbation between 17 healthy athletes and 17 athletes who recently experienced low back pain. Sudden perturbations were applied in the following four directions: flexion, extension, left and right lateral bending. The muscle recruitment patterns were different between healthy athletes and athletes with low back pain. Athletes with low back pain exhibited

longer latency than healthy ones. Authors concluded that the recently injured athletes retained the neuromuscular impairments.

Stokes et al. (2006) also investigated the muscle recruitment patterns and muscle reflex responses for 21 subjects with low back pain and compared them to 23 healthy participants using sudden force perturbations. Participants performed ramped tests and force perturbation tests while seated in an apparatus with immobilized pelvis. Resistance was provided by a cable passing through a pulley with five anchor points on the surrounding walls to the participant at 0°, 45°, 90°, 135° and 180° to the anterior direction. The level of the cable was maintained horizontal at the level of T12. Results showed higher muscle pre-activation among people with low back pain compared to healthy people. The maximum effort was found to be lower for low back pain participants (403 N) compared to healthy participants (575 N). Authors attributed this to factors such as pain inhibition, lack of motivation, and anatomical differences.

2.3.2 Muscle reflex in neck/cervical spine

Compared to the extensive reflex response research on the lumbar spine, limited research is available for the cervical spine.

2.3.2.1 Load and preload effect

Viviani and Berthoz (1975) examined the dynamics of head-neck system in response to small load perturbations (15 N maximum). Participants in a restrained seated position were exposed to sudden perturbations. Sinusoidal (0.6–20 Hz) and impulsive forces were applied in the sagittal plane for 100 msec. The head kinematics and kinetics were recorded to compute the impulse transfer function to quantify the head-neck dynamics parameters. Frequencies below 2 Hz were observed to produce distorted displacement. However, head displacement was almost linear at frequencies above 2 Hz. The results indicated that the system behaves as a second order system with two degrees of freedom. Authors grouped the passive properties and neuronal control system as viscoelastic system that consists of stiffness and viscosity. Both viscoelastic parameters were found to increase with the continuous increase of load at frequencies above 2Hz.

Tangorra et al. (2003) investigated the head-neck system dynamics under the effect of static torque in the horizontal plane using sudden perturbations. Static torque of zero to 0.65 Nm with an increment of 0.05 Nm was applied to the head using helmet-based perturber in the

clockwise and counter-clockwise directions. Findings indicated that at constant torque, the head-neck system behaved as a second-order, under-damped, passive system. Both effective stiffness and damping increased as the static torque magnitude increased.

Simoneau et al. (2008) examined the effect of preload on head stability using sudden perturbations. Seven healthy participants (4 males and 3 females) were exposed to sudden head perturbations using 1 kg load in the backward and forward directions at different preload conditions (0.22, 0.44, 0.66, 0.88 N). Participants were seated on a chair with a four-point strap to restrain the back and minimize its contribution to the head-neck system. The forward perturbations moved the head forward (flexed) while the backward perturbations pushed the head backward (extended). The preload was attached to the headband by a cable. A cable ran over a pulley to connect the headband with the preload. The load is controlled by an electromagnet and the deactivation of the electromagnet released the load and triggered the sudden perturbations. Authors hypothesized that adding load to the head will reduce its angular velocity. Accordingly, the reduction of the angular velocity would lead to an increase in the muscle stiffness and consequently to a more stable spine. Neck viscoelastic properties were estimated using a 2nd order linear model. Results showed that the head angular velocity decreased with the increase in the preload magnitude for both the backward and forward perturbations. Also, the head angular velocity was not affected by both the direction of perturbation and the interaction between preload and the direction of perturbation. With the increase of the preload magnitude the head angular velocity increased. Both the effective stiffness and viscosity increased as the preload magnitude increased. However, both of them were not affected by the direction of perturbations. In summary, as the head angular velocity decreased, the stability of the head-neck system improved.

Forbes et al. (2012) studied the influence of torso perturbations on the neck reflex responses. Twelve healthy participants (3 females) in a restrained seated position, wearing a light weight helmet underwent variable bandwidth sudden perturbations (0.3 Hz and up to 1.2, 2, 4 and 8 Hz) at three amplitudes. Trials were repeated with open and closed eye. Neck muscle EMG and head kinematics were recorded to obtain frequency response functions. The frequency response functions were shown to be dependent on bandwidth and vision and minimally on the amplitude. The vestibulocollic (VCR) and cervicocollic (CCR) reflexes, which are important to stabilize the head-neck system, were attenuated as the bandwidth exceeded the system's natural

frequency. This caused a shift in the stabilizing system from head-neck in space to head-on-trunk. Moreover, the reflexes attenuated further when the eyes were closed, as a result minimized ability to distinguish self-motion, shifting the system to the head-trunk. In general, perturbation bandwidth and vision status alter VCR and CCR reflexes to maintain head stability in the up-right posture.

2.3.2.2 Whiplash injury

Whiplash injury has become a significant public health problem. Consequently, whiplash-like perturbations have been widely used to investigate the dynamics and behavior of the head-neck system. Several whiplash studies reported shorter latencies of 67-81 msec in the sternocleidomastoid muscle (Kaneoka et al. 1999, Magnusson et al. 1999, Brault et al. 2000, Siegmund et al. 2003) compared to voluntary latencies computed during forewarned reaction-time studies (107 msec) (Mazzini and Schieppati 1992, Siegmund et al. 2001). Kumar et al. (2002) reported higher neck EMG activity during whiplash-like perturbations, especially in the sternocleidomastoid muscle. The sternocleidomastoid muscle generated 179% of maximum voluntary contraction, while the splenii and trapezii muscles did not go over 37% of the maximum voluntary contraction. They also observed higher EMG activity and shorter latencies at higher accelerations.

Siegmund et al. (2003) studied the effect of the awareness on the neck EMG and head kinematics during whiplash-like perturbations. Their results showed that surprised subjects exhibited larger cervical paraspinal muscles amplitude and higher angular head accelerations in flexion than unaltered participants. Siegmund et al. (2003) also investigated the effect of the repeated whiplash-like perturbations on the neck muscles activity and head kinematics. Findings indicated that cervical paraspinal EMG was significantly reduced by the 2nd perturbation while the sternocleidomastoid EMG was reduced by the third perturbation. Head kinematics represented by acceleration was also changed between perturbations. Authors indicated that results from previous studies that used repeated perturbations to investigate whiplash injury may be confounded by habituation.

Sacher et al. (2012) studied the head-neck musculoskeletal system reflex dynamics during sudden perturbations in different directions. Ten participants with back and shoulder being secured in seated position were exposed to equal magnitude sudden head perturbation in 4 directions

(anterior, posterior, left and right). Perturbations were created using a parallel robotic platform. The sternocleidomastoid, trapezius, and splenius capitus muscles EMG activity and Kinematics of the head, thorax, and head relative to thorax were recorded. The focus was on the sternocleidomastoid muscle since the trapezius and splenius capitus muscles showed less than 5% of the maximum voluntary contraction. The reflex onset latency for the sternocleidomastoid muscle during the anterior, posterior, right and left perturbation was 143, 30, 55, and 65 msec, respectively. Also, the greatest linear head acceleration was observed in the posterior perturbations. The results indicate that the sternocleidomastoid muscle plays a crucial role during whiplash response and suggest that rear perturbations have a greater risk for head-neck injury than the other directions.

2.3.3 Muscle reflex in lower limbs

Dietz et al. (1989) investigated lower limbs muscle reflex response to sudden perturbation by exposing subjects walking on a treadmill to a suddenly accelerating split belt. Perturbations were found to be unilateral or bilateral in the same or opposite directions. Results also showed rapid responses initiated in both perturbed and unperturbed leg. However, responses occurred earlier in the perturbed leg. During bilateral perturbations, the response magnitude depended on the direction of perturbation (same or opposite). The net response magnitude in the same direction was the sum of two responses magnitude, while the net response magnitude in the opposite direction was the difference between responses. Consequently, muscle responses could be significantly modulated to change muscle forces to maintain the center of gravity over the base of support to prevent potential falls.

Series of studies conducted by Kearney et al. (Kearney and Hunter 1982, Kearney and Hunter 1988, Kearney and Stein 1993, Stein and Kearney 1995, Kearney *et al.* 1997) investigated the dynamics and behavior of human ankle stiffness using sudden perturbations. The reflex stiffness was found to be behaving nonlinearly and its contribution to the ankle joint stability varies based on the task performed.

Kearney et al. (1997) studied the reflexive stiffness in human ankle using sudden perturbation. Participants (n = 8 males) lay supine with ankle set at 90 degrees angle and left foot connected to a pedal of an electro-hydraulic actuator (position servo). The ankle was exposed to low amplitude sudden displacement pulse. During that subjects were instructed to

perform a constant level of tonic contractions of the gastrocnemius-soleus at a level equivalent to 10% of the maximum voluntary contraction without resisting the perturbations. Intrinsic stiffness was identified as a second-order linear system. A parallel-cascade, nonlinear system identification technique was used to separate overall stiffness into intrinsic and reflexive stiffness. Findings indicated that reflexive stiffness was most important at a frequency between 5 and 10 Hz. The reflex gains decreased as the mean velocity of the perturbation increased.

Mirbagheri et al. (2000) examined the intrinsic and reflex contributions to human ankle stiffness using sudden perturbations. Thirteen participants lay supine with their foot connected to the pedal of an actuator by custom-fitted glass-fiber boots. The knee underwent a sudden perturbation while it was held fully extended. The EMG activity from the gastrocnemius and tibialis anterior were recorded in addition to the knee kinematics and kinetics. A parallel-cascade, nonlinear system identification technique was used to separate overall stiffness into intrinsic and reflexive. Despite the variability between subjects in regard to the absolute magnitude of intrinsic and reflex stiffness parameters, the relative changes with contraction level and position were consistent. Intrinsic stiffness increased with the contraction level, while the reflex stiffness was maximal at low contraction level. However, both of them increased as the ankle was dorsiflexed. Consequently, the biggest contribution of the reflex component was near the neutral posture at low level of activity. Despite the variability in the maximum reflex contribution between subjects (1-55%) it played a significant role in knee stability.

Zhang et al. (1999) investigated the patellar reflexes using sudden perturbation. Fourteen participants (12 healthy and 2 symptomatic) in the upright seated position were exposed to sudden perturbations using a hammer tapping on amounted dome-shaped rubber pad on the most sensitive spot of the patellar tendon. Force data, the quadriceps EMG activity and knee joint extension torque signals were recorded to calculate muscle reflex response parameters. The following parameters were identified to quantify the reflex dynamics: tendon reflex gain; contraction rate; and half-relaxation rate and reflex loop delay. These parameters were calculated using the impulse response function relating torque to force and the impulse response function relating EMG to force. Sensitivity and consistency calculations suggested that these parameters may accurately quantify reflex dynamics when the appropriate simplification of the instrumentation is applied.

2.3.4 Muscle reflex in upper limbs

Upper limbs reflex response especially the long latency responses were shown to be task dependent in the several studies (Akazawa et al. 1983, Kanosue et al. 1983, Colebatch and McCloskey 1987, Hore et al. 1990, Doemges and Rack 1992b, Perreault et al. 2006). In these studies, participants were asked to maintain a fixed position or a constant force. When sudden perturbations were used to test muscle reflex response, participants showed a higher reflex response to perturbations when stabilizing a position rather than force. This was due to the higher firing rate of the motor units during the position control compared to the force control.

Hore et al. (1990) investigated the reflex responses of the wrist flexors, while anaesthetized, based on the task (position or force control) using sudden perturbations. In the position task, results showed increased co-contraction of antagonist muscles as a mechanism to improve reflex response, and indicated that changes in the reflex gain is responsible for the modulation in the reflex response. Similar task dependent results were reported in other parts of the upper limb, such as the finger (Doemges and Rack 1992a), the wrist (Doemges and Rack 1992b) and the elbow (Dietz et al. 1994).

The aforementioned studies focused on observing the reflex response of a few muscle at a single joint using sudden perturbation. The applied perturbation at a single joint can cause a response (displacement) of several adjacent muscles at multiple joints. This behavior was investigated by Lacquaniti et al. (1986) and Soechting et al. (1988) using sudden perturbation applied to the shoulder area. As a result of the sudden perturbation, muscle reflex responses were observed in both the shoulder and elbow flexors. Authors suggested that perturbation applied to the shoulder triggered restoring extensor torques at the elbow. Consequently, the elbow flexors initiated reflexes to compensate for the effects of the extensor torque. Multijoint effects were also studied using perturbations by Gielen et al. (1988) and Jongen et al. (1989), and recently replicated by Kurtzer et al. (2008) . Kurtzer et al. (2008) concluded that sudden perturbation to the shoulder caused reflex responses at both the shoulder and elbow joints. The long latency for the shoulder was triggered by both shoulder and elbow kinematics to compensate for the multijoint torque pattern rather than local muscle stretch.

Perreault et al. (2008) investigated the effect of compliant loads on the stretch reflex gains using multijoint sudden perturbation. They also showed similar reflex coordination

patterns stated in the aforementioned studies in response to multijoint perturbations. Despite the recruitment of similar muscles in response to both the stiff or compliant environment in the task, the magnitude of reflex activation was quite different. This is due to the flexibility of reflex coordination patterns during multijoint task. In summary, the multijoint reflex coordination patterns are task dependent and have the flexibility to modulate based on the task demands (task-specific reflex modulation).

Zhang and Rymer (2001a) examined the effect of fatigue on intrinsic and reflex responses of the human elbow using sudden perturbation. Five normal participants sat upright in a customized seat with neutral arm posture. Fatigue was induced by performing 15 min of intermittent voluntary isometric (submaximal) exercise, followed by 10 min rest to recover from acute fatigue effect. Subjects underwent sudden perturbation pre and post-fatigue. Elbow flexion angle, perturbing torque, and EMG signals from the lateral, medial, and long heads of the triceps, anconeus, and biceps muscles were recorded. A decrease in joint stiffness and static reflex gain at high torque levels was observed post-fatigue. However, dynamic reflexes (stiffness and reflex gain) increased after fatigue to compensate for the reduction in the intrinsic stiffness. An earlier study by Kirsch and Rymer (1992) reported similar results when investigated the effect of fatigue on intrinsic and reflex muscle response for elbow joint. They also reported that when using a wide bandwidth perturbation (0 – 25 Hz), fatigue had no effect on the intrinsic stiffness due to the disabled force generation in elbow flexor muscles. However, for a perturbation with a smaller bandwidth (0 – 10 Hz), fatigue caused a consistent decrease in the intrinsic stiffness.

CHAPTER THREE: RATIONALE AND OBJECTIVES

Musculoskeletal disorders (MSDs) of the neck are common. Etiologies of the MSDs of the neck and cervical spine are believed to be multidimensional, with physical work demand, psychosocial factors, and individual factors contributing significantly to the cause of disorder (Ariens et al. 2000, Von Korff et al. 2005). Physical work demands, such as sustained static postures, sub-maximal repetitive arm exertions, and forceful arm exertions are consistently identified as probable risk factors for MSDs of the neck and cervical spine in the epidemiological and empirical studies (Ariens et al. 2000, Ariëns et al. 2001, Cagnie et al. 2007). Most of these exertions generate localized muscle fatigue which may affect the stability of the cervical spine (Veiersted 1994, Björkstén et al. 2001). Currently, the effect of muscular fatigue on the stability of the cervical spine is not well understood. A critical need exists to better understand the effect of fatigue on the stability of the cervical spine. The possible mechanism of the pathogenesis of neck and/or cervical spine MSD could be identified by understanding the post-fatigue changes in the stability of the cervical spine. Understanding the patho-mechanism of neck and/or cervical spine MSDs is crucial, as neck disorders are common among the workers of almost all the National Occupational Research Agenda (NORA) sector groups (Myers 2006).

The objective in this study was to quantify the post-fatigue changes and recovery of the cervical spine stability. Specifically, the flexion-relaxation phenomenon (FRP) and sudden perturbations (SP) procedures were used to study the variables that influence the stability of the cervical spine. The spine stability is controlled by: (1) baseline muscle activation, (2) passive (ligaments, discs and bones) structure, and (3) active feedback from muscle reflex (Panjabi 1992a). The baseline recruitment of active muscles and the load sharing between active and passive tissues were measured by studying the following variables that characterize the cervical flexion-relaxation phenomenon:

- 1) Flexion-relaxation ratio (FRR)
- 2) Onset and offset angles of the silence period
- 3) Expansion of the silence period

The muscle reflex behavior was evaluated by studying the response of the cervical spine to sudden perturbations using the following variables:

- 1) Spine stiffness
- 2) Reflex gain
- 3) Reflex onset delay or latency
- 4) Time to peak
- 5) Peak to peak time
- 6) Reflex amplitude

These variables were derived using the neck muscle activation, head-neck motion and force data. Surface electromyography (EMG) and optical motion capture systems were used to record neck muscle activation and head-neck posture, respectively. Additionally, a six degree of freedom force torque sensor was used to record the force profile during the sudden perturbation protocol. Neck muscle fatigue was induced by using the Sorenson protocol and the variables that showed significant post-fatigue changes were further assessed to evaluate their recovery behavior. The recovery behavior was measured during the rest period at 0, 15, 30, 45 and 60 minutes.

The central hypothesis was that the muscular fatigue would affect the stability of the cervical spine. The specific hypothesis statements for different stability related variable were as follows:

H₀₁: Flexion relaxation ratio would not be affected by the fatigue

H_{A1}: Flexion relaxation ratio would decrease post-fatigue

H₀₂: Silent period onset angle would not be affected by the fatigue

H_{A2}: An early silent period onset angle would be observed post-fatigue

H₀₃: Silent period offset angle would not be affected by the fatigue

H_{A3}: A delayed silent period offset angle would be observed post-fatigue

H₀₄: The duration of silent period would not be affected by the fatigue

H_{A4}: The duration of silent period would increase post-fatigue

H₀₅: Spine stiffness would not be affected by the fatigue

H_{A5}: Spine stiffness will decrease post-fatigue

H₀₆: Reflex gain of cervical extensors would not be affected by the fatigue

H_{A6}: Reflex gain of cervical extensors would decrease post-fatigue

H₀₇: Reflex delay of cervical extensors would not be affected by the fatigue

H_{A7}: Reflex delay of cervical extensors would increase post-fatigue

H₀₈: Time to peak cervical extensors activation would not be affected by the fatigue

H_{A8}: Time to peak cervical extensors activation would increase post-fatigue

H₀₉: Peak to peak time between external perturbation force and internal cervical extensors activation would not be affected by the fatigue

H_{A9}: Peak to peak time between external perturbation force and internal cervical extensors activation would increase post-fatigue

H₀₁₀: Reflex amplitude of cervical extensors would not be affected by the fatigue

H_{A10}: Reflex amplitude of cervical extensors would decrease post-fatigue

In addition to the fatigue, the influence of gender on the stability of cervical spine was studied by testing the following central hypotheses:

H_{G-01}: Flexion relaxation ratio would not be affected by the gender

H_{G-A1}: Higher flexion relaxation ratio would be observed for females than males

H_{G-02}: Silent period onset angle would not be affected by the gender

H_{G-A2}: An early silent period onset angle would be observed for males than females

H_{G-03}: Silent period offset angle would not be affected by the gender

H_{G-A3}: A delayed silent period offset angle would be observed for males than females

H_{G-04}: The duration of silent period would not be affected by the gender

H_{G-A4}: Higher duration of silent period would be observed for males than females

H_{G-05}: Spine stiffness would not be affected by the gender

- H_{G-A5}: Higher spine stiffness would be observed for males than females
- H_{G-06}: Reflex gain of cervical extensors would not be affected by the gender
- H_{G-A6}: Higher reflex gain of cervical extensors would be observed for females than males
- H_{G-07}: Reflex delay of cervical extensors would not be affected by the gender
- H_{G-A7}: Higher reflex delay of cervical extensors would be observed for males than females
- H_{G-08}: Time to peak cervical extensors activation would not be affected by the gender
- H_{G-A8}: Higher time to peak cervical extensors activation would be observed for males than females
- H_{G-09}: Peak to peak time between external perturbation force and internal cervical extensors activation would not be affected by the gender
- H_{G-A9}: Higher peak to peak time between external perturbation force and internal cervical extensors activation would be observed for males than females
- H_{G-010}: Reflex amplitude of cervical extensors would not be affected by the gender
- H_{G-A10}: Higher reflex amplitude of cervical extensors would be observed for females than males

The rationale for the proposed research was that, once the post-fatigue changes in the stability of cervical spine and its recovery is understood, this knowledge is expected to improve our understanding of fatigue related impairment of the cervical spine. Innovativeness of this work lies in being able to explore several variables that are traditionally related to the stability of the spine in order to determine the most significant ones for the cervical spine. The FRP reflects the load sharing between active and passive tissues and the SP protocol allows for the study of reflexive behavior of the active tissues. The successful completion of the proposed work is expected to improve our overall understanding of the characteristic changes in the behavior of the variables that influence post-fatigue stability of the cervical spine. Based on this improved understanding workplace methods, especially work-rest models can be appropriately modified to reduce the incidence of excessive fatigue, further preventing neuromuscular impairment and resulting neck MSDs.

CHAPTER FOUR: METHODOLOGY

The effect of neck muscle fatigue on the stability of the cervical spine was quantified by testing human participants. The spinal stability is usually achieved by a highly coordinated interaction of active and passive components of the neuromuscular systems. In this study, the flexion-relaxation phenomenon (FRP) and sudden perturbation (SP) protocols were used to examine the post-fatigue changes in the stability of the cervical spine. Consequently, the recovery behavior of these variables was also evaluated. Neck muscle fatigue was induced by using the Sorenson protocol.

4.1 Participants

Twenty healthy participants (10 male and 10 female) were recruited to participate in this study. A summary of the participants' demographic data is presented in Table 1. The primary inclusion criteria used in this study requires that the participants were free from any type of musculoskeletal, degenerative or neurological disorders and had no history of neck, back, and shoulder injury or notable pain. The Physical Activity Readiness Questionnaire (PAR-Q, Canadian Society for Exercise Physiology) was used to screen participants for cardiac and other health problems (e.g., dizziness, chest pain, heart trouble) (Appendix B). Participants who met the inclusion criteria were asked to read and sign a consent form approved by the local Institutional Review Board (Appendix A).

Table 1: Participants demographic data

Gender	Age (year)	Height (cm)	Weight (Kg)
Female	29.1 $\pm$ 3.9	162.9 $\pm$ 6.3	56.2 $\pm$ 7.7
Male	24.1 $\pm$ 2.4	175.6 $\pm$ 6.3	70.5 $\pm$ 7.6
Total	26.6 $\pm$ 4.2	169.3 $\pm$ 9.2	63.4 $\pm$ 10.7

Statistical power for the proposed sample size was calculated for the FRP parameters. In one of our preliminary studies, the effect of fatigue on FRP parameters was tested. The statistical power for these FRP variables was estimated using the operating characteristics

curves (OC curves), a graph of β (type II error probability) versus the true difference in means, using the following equation:

$$\phi = \sqrt{\frac{n\delta^2}{2K\sigma^2}} \quad \dots\dots\dots (1)$$

$$v1 = K - 1 \quad \dots\dots\dots (2)$$

$$v2 = K(n - 1) \quad \dots\dots\dots (3)$$

Where,

Φ : Noncentrality parameter

n: Sample size

δ : Minimum detectable difference (i.e. the smallest difference we wish to detect between the pre and post-fatigue means

K: Number of levels

σ^2 : Variance of the population

v1: Degrees of freedom for the means (levels)

v2: Degrees of freedom for the error

The δ and σ^2 values for the three FRP variables, calculated using the preliminary study, are shown in Table 2.

Table 2: δ & σ^2 values for the FRP parameters

Variable	δ	σ^2
Flexion relaxation ratio (FRR)	1.291938	0.538248
Onset angle	0.129238	0.003417
Offset angle	0.014472	7.48E-05

For Flexion relaxation ratio (FRR), a sample size of 8 provided approximately 90% chance of rejecting the null hypothesis (Table 3). Increasing the sample size to 10, would increase the power close to 96%. For the onset angle a power close to 98% was observed for a

sample size of 8 (Table 4). For the offset angles, a sample size of 8 provided approximately 88% chance of rejecting the null hypothesis and increasing the sample size to 10 would increase the power close to 94% (Table 5).

Table 3: FRR power and sample size calculations

n	v1	v2	Φ	Power
8	1	14	2.490379	0.90
9	1	16	2.641446	0.94
10	1	18	2.784329	0.96

Table 4: Onset angle power and sample size calculations

n	v1	v2	Φ	Power
8	1	14	3.126738	0.98
9	1	16	3.316406	
10	1	18	3.495799	

Table 5: Offset angle power and sample size calculations

n	v1	v2	Φ	Power
8	1	14	2.367195	0.88
9	1	16	2.51079	0.91
10	1	18	2.646605	0.94

For the variables related to the sudden perturbation and gender effect, the power of the statistics could not be accurately predicated due to unknown variances. Previous studies evaluating the effect of sudden perturbation on the stiffness of the lumbar spine have used anywhere from 9 to 20 participants (Granata et al. 2005, Lee et al. 2006, Granata and Rogers 2007, Moorhouse and Granata 2007, Hodges et al. 2009, Hendershot et al. 2011). For gender comparison, 12 to 17 participants (almost 50% female) were used (Granata et al. 2005, Granata and Rogers 2007, Hodges et al. 2009, Hendershot et al. 2011). Based on these studies and the

results of the preliminary study, a sample size of 10 participants per gender was deemed adequate for the current study.

4.2 Apparatus/tools

The following pieces of equipment were used in this research:

4.2.1 Custom-built sudden perturbation workstation: This device consists of a wooden chair, force/torque (F/T) sensor, light weight braided steel cable, low friction pulley system, pre-load, dropping load, and electromagnet (Figure 5, 6 & 7).

Figure 5: Custom-built workstation: (a) column assembly base, (b) four-point harness (c) wooden chair, (d) head rest, (e) steel cable, and (f) adjustable headband

Figure 6: Column assembly column: (a) pulley, (b) measuring tape, (c) force sensor, (d) electromagnet, (e) load, (f) preload, and (g) mux box

Figure 7: Column assembly base components: (a) pulley, (b) force sensor, (c) electromagnet, (d) load, and (e) preload

The force profile during sudden perturbation was measured using a six component F/T sensor system (ATI Industrial Automation, Inc., Apex, NC, USA). One end of the F/T sensor connects to the head of the participant using light weight braided steel cable which passes through a low friction pulley system. An adjustable head band is used to attach the steel cable to the head of the participant. The other end of the F/T sensor connects to the fixed pre-load (0.5

kg). The pre-load is necessary to prevent injury by initializing the stabilizing mechanisms of the cervical spine (Simoneau, et al., 2008). The steel cable that connects the F/T sensor to the pre-load passes through a cylindrical opening in the dropping load (1 kg). The position of the dropping load is controlled at 5 cm above the preload. The dropping load is mounted using an electromagnet. A push-button release is used to deactivate the electromagnet and upon deactivation, the electromagnet releases the dropping load on top of the preload resulting in an impulse force (sum of load and preload) causing forward perturbation of the participant's head. The pulley system and the load mounting (electromagnet) mechanism are height adjustable to standardize setup across participants. The force data during forward perturbation was measured at a frequency of 1000 Hz.

4.2.2 Electromyography (EMG) system: A Bagnoli-16 desktop EMG system (Delsys Inc., Boston, USA) was used to collect the muscle activation data of the neck extensors. The system consists of a main amplifier unit, an input module, EMG electrodes, and other peripheral cables. Figures 8 & 9 show the system parts.

Figure 8: Bagnoli system components: (a) main amplifier unit, (b) input modules, and (c) surface electrodes

Figure 9: Bagnoli system components: (a) reference electrode with tip and banana connectors, (b) input cable, and (c) power supply unit

The input modules host the surface and reference EMG electrodes. Each unit can carry up to eight electrodes. The input module supplies power to the electrodes and communicates the EMG signal detected by the electrodes with the main amplifier unit via the input cable. Each input module has a clip on one side to facilitate its mounting on to waist belts or other articles of clothing. The main amplifier unit (desktop unit) receives and conditions the signals transmitted by the input module. It has a band pass filter of 20 to 450 Hz, and a mechanism to check for excessive amounts of line interference. The analog channel outputs from this unit are sent directly to the optical motion capture system (Vicon Nexus) software using an analog to digital (A/D) acquisition system.

The EMG signal is the result of the potential difference between the two electrodes (V1 & V2) on the skin surface with respect to the electrical potential of a neutral surface (Commonly the reference electrode) located away from the EMG muscle location (Figure 10). The reference electrode has a tip connector to connect with the input module via a banana connector (Figure 9a).

Figure 10: EMG surface electrodes diagram

The surface electrodes used for data acquisition are parallel bar-active surface electrodes (DE-2.3 EMG Sensors, Delsys Inc., Boston, USA). The electrode housing is constructed with waterproof polyurethane plastic and the electrode sensor contacts are made from 99.9% pure silver bars, measuring 10 mm in length, 1 mm in diameter and spaced 10 mm apart for optimal signal (Figure 10). The CMRR for the electrodes is 92 dB with input impedance greater than $10^{15} \Omega$. A frequency of 1000 Hz was used to collect the EMG data.

4.2.3 Optical Motion Capture System: Vicon motion capture system (Vicon Motion Labs, Oxford, UK) was used to capture the head-neck motion during FRP and SP procedures. This

system consists of eight optical cameras (MX-Series) with infrared strobes (Figure 11) that emit infrared light which reflects off of small retro-reflective markers. The cameras capture the reflected light and record the location of the markers in 3D space. The data-station (Figure 12) controls the cameras and facilitates data collection on a PC using the Vicon Nexus 1.8.1 software (Vicon Motion Labs, Oxford, UK). This software allows processing of marker data (e.g. labeling, gap filling, filtering) to compute 3D marker coordinates. Marker data was sampled at a rate of 100 Hz.

Figure 11: Infrared camera & retro-reflective markers

Figure 12: Data-station

4.2.4 Force/Torque (F/T) Sensor System: The external force during sudden perturbation protocol was measured by using a six components force and torque (F_x , F_y , F_z , T_x , T_y , and T_z) sensor system (ATI Industrial Automation, Inc., Apex, North Carolina USA) (Figure 13). The system consists of the following parts:

4.2.4.1 Mini 45 F/T Sensor (Figure 6, 7b & 14a): This is a compact, rugged, monolithic transducer that uses strain silicon gages to convert force and torque into analog strain gauge signals.

The transducer's silicon strain gauges provide a high signal-to-noise ratio (near-zero noise distortion) and a high overload protection. It has an output rate of 7000 Hz, 288 μ sec latency, 5 to 838 Hz digital filtering and 1st order at 1000 Hz anti-aliasing filtering capability. This sensor is connected to the Mux Box through a 16-pin twist-to-lock connector (Figure 14b). The F/T sensor can be used in two calibration settings; 145N & 290N (Table 6). In this research the maximum force that was produced during the sudden perturbation procedure ranged from 50-60 N. Therefore the F/T sensor was used in the 145N setting.

Figure 13: F/T Sensor system components

Figure 14: F/T sensor system component: (a) F/T sensor mini 45, (b) 16-pin twist-to-lock connector, and (c) mux-box

Table 6: F/T sensor-two calibration settings

	SENSING RANGES				RESOLUTION*			
Calibration	Fx,Fy	Fz	Tx,Ty	Tz	Fx,Fy	Fz	Tx,Ty	Tz
SI-145-5	145 N	290 N	5 Nm	5 Nm	1/16 N	1/16 N	1/752 Nm	1/1504 Nm
SI-290-10	290 N	580 N	10 Nm	10 Nm	1/8 N	1/8 N	1/376 Nm	1/752 Nm

4.2.4.2 Mux Box (Figure 14c): Contains transducer electronics that can't be housed in the transducer due to its small size. A 15-pin D-subminiature connector, called Mux-box cable, connects the F/T sensor with the Mux Box (Figure 13). This box is also provided with a switch (Figure 14c) to flip between the two calibrations settings (145 or 290N).

4.2.4.3 F/T Controller (Figure 13): Converts the strain gauge data from the F/T sensor into Cartesian force/torque components (XYZ Components). The analog output of the F/T

Controller is communicated to the A/D board of the Vicon Nexus system. It has an output rate of 2500 Hz, 800 μ sec latency, averaging filter option and 2nd order at 235 Hz anti-aliasing filtering capability.

4.3 Experimental Design

The effect of fatigue on the stability of the cervical spine was tested by performing the FRP and SP procedures. These procedures were performed at the start of the experiment (pre-fatigue), followed by the Sorenson protocol. Immediately after the Sorenson protocol, the FRP and SP procedures (post-fatigue) were repeated. During the rest period, the FRP and SP procedures were repeated at 15, 30, 45 and 60 minutes.

4.3.1 Flexion Relaxation Phenomenon: The flexion-relaxation phenomenon explains the synergistic load sharing between the muscles and viscoelastic elements (ligaments, discs, capsules, and fascia). During head flexion, cervical extensors gradually increase their activation to compensate for the increasing effect of gravity on the mass of head. In the fully flexed posture, the strained viscoelastic elements generate force sufficient to offset the effect of gravity, resulting in a reduced activation of the extensors (Meyer et al. 1993). The FRP for cervical spine was first reported by Meyer et al. (1993). Subsequently a number of studies compared symptomatic individuals with healthy controls using FRP parameters. To study the variables related to the FRP, the participants in the current study started with a neutral head-neck position (Phase 1), fully flexed the neck with a goal of approximating their chin to their upper chest (manubrium) within 5 seconds (Phase 2), maintained full flexion for 5 seconds (Phase 3), and extended their neck to the neutral position within 5 seconds (Phase 4) (Figure 15). Participants' movement was controlled using a metronome with audible sound. This procedure was repeated at least 3-times pre- and post-fatigue.

4.3.2 Sudden perturbation procedure: The sudden perturbation procedure was used to quantify the functional contribution of muscles reflexes in spine/joint stability by applying unexpected force disturbances. The spine/joint systems respond to perturbations in a synchronized manner by first achieving the peak displacement followed by a state of equilibrium. The post perturbation spinal/joint stability is usually achieved by the adjustment in the behavior of active tissues to alter structural stiffness and viscosity.

Figure 15: EMG and kinematic data during cervical a flexion-extension trial and the corresponding FR phases and parameters.

In general, the human spine is expected to react to perturbations as an underdamped second order model that includes stiffness, damping and effective mass. To perform the sudden perturbation, the custom-built sudden perturbation workstation was used. The participants were stabilized in the chair of this workstation and their head was exposed to sudden (unexpected) forward perturbation. A dropping load of 1kg was used to generate the sudden perturbation using an electromagnet system (Simoneau et al. 2008). This perturbation procedure was repeated at least 3 times before and after the fatigue.

4.3.3 Fatigue protocol: The Sorenson protocol was used to induce neck muscular fatigue (Lee et al. 2004, Lee et al. 2005). The participants were asked to lay prone on a table with arms on the sides and shoulders (acromion) level with the edge of the table (Figure 16). In this research, a pendulum (Figure 16 & 17) with a load of 0.5 kg was used to accelerate the process of fatigue induction. The pendulum was attached to the forehead using a Velcro strap (Figure 16). Muscular fatigue was induced as a consequence of exposing head and neck to the gravitational forces. Participants were encouraged to maintain this position as long as possible. To guarantee participants' safety, the level of neck discomfort and pain was monitored during the Sorenson protocol every minute using a CR-10 Borg discomfort scale (Figure 18). The Borg CR-10 scale contains two columns, one for subjective categories ranging from "nothing at all" to "extremely strong" and the other for numerical ratios ranging on a scale of 0 to 10 that are associated with the different categories. The Sorenson protocol was discontinued when participants reached a score of 8 on the Borg scale.

Figure 16: Sorenson protocol

Figure 17: Pendulum

Borg's CR-10 scale		
0	Nothing at all	
0.5	Extremely weak	(just noticeable)
1	Very weak	
2	Weak	(light)
3	Moderate	
4		
5	Strong	(heavy)
6		
7	Very strong	
8		
9		
10	Extremely strong	(almost max)

Figure 18: Borg's CR-10 scale.

4.4 Data Collection

4.4.1 Participant orientation & measurement: Each participant was introduced to the equipment, experimental set-up, and specifics of experimental tasks. The demographic and anthropometric measurements were recorded (Appendix C).

4.4.2 EMG data collection preparation: First, the skin where the electrodes were placed was shaved (if needed), abraded, and cleaned with 70% alcohol pads. After that, two surface electrodes were placed bilaterally at the C4 level (approximately, the mid region of the cervical spine) to measure the neck extensors EMG activity (Figure 19a). The C4 level was determined by drawing a horizontal line above the C7 level at 2.5 times a distance between the C6-C7 vertebrae. The electrodes were placed parallel to the muscle fiber (approximately 35° to the

vertical line between C7 and C4) (Nimbarte *et al.* 2010, Nimbarte 2014) (Figure 19a). The reference electrode was placed on the right side of the forehead (Figure 19b & c).

Figure 19: Different view angles of markers and electrode placement (a) rear view, (b) front view, and (c) side view

4.4.3 Actual Data Collection: Once fitted with the surface electrodes and markers, the participants were stabilized in the chair of the custom-built perturbation workstation. Baseline FRP readings were obtained during the head flexion-extension motions. Subsequently, the participants were exposed to the sudden perturbations. The headband was mounted on the participant and the height of the pulley was adjusted so that it was directly in front of the headband. The participants were instructed to relax and maintain their head still in a neutral position. To avoid any visual feedback, participants were asked to close their eyes before, during and after perturbation. To avoid audio feedback, participants were asked to listen to music using headphones during the perturbation procedure. When the participants seemed to be in a relaxed seating position, the electromagnet was deactivated to release the load resulting in sudden forward perturbation of the head. Next, the Sorenson protocol was used to induce neck muscle fatigue. The EMG data was recorded at the end of every minute during the Sorenson protocol. The procedure for FRP and sudden perturbation was repeated post-fatigue at 0, 15, 30, 45 and 60 minutes.

4.5 Data Processing and Analysis

4.5.1 EMG data: The raw EMG data recorded during the FRP and SP procedures were demeaned and then full-wave rectified. The full-wave rectified EMG signal was then low pass filtered at 4 Hz using a fourth-order Butterworth digital filter, to form a linear envelope (Burnett *et al.* 2007). The EMG data recorded during the Sorenson protocol was transformed from the

time domain to frequency domain using Fast Fourier algorithm. The power density spectrum of the transformed data was analyzed by using median frequency and the power of different frequency bands (8-16, 16-32, 32-63, 63-125, 125-250 and 250-500 Hz).

4.5.2 Motion data: The Vicon Nexus 1.8.1 software was used to process the raw marker data (Figure 20a). Each maker had a unique name based on its location on the body. In this research a label for a marker placed in the forehead region was FHD (Figure 20b). The labels for the markers on the right and left sides of the head were RHD and LHD, respectively (Figure 20b). After all the markers were labeled, gaps in the marker data were filled by selecting appropriate gap filling algorithms: pattern-fill, split-fill and Woltring gap-filling. While the pattern-fill and split-fill algorithms are used to fill one gap at a time, the Woltring gap-filling algorithms can fill longer (up to 5 frame limit) gaps. The marker data was then low pass filtered at 4 Hz using a 4th order Butterworth filter and subsequently exported as XYZ coordinates for further analysis.

Figure 20: (a) raw markers data, and (b) processed markers data

The XYZ coordinates collected during the sudden perturbation procedure were used to track the head motion in the X-direction by computing the midpoint of two TMJ markers. The midpoint of these two points was chosen, because it approximately represents the center of mass for the head. The XYZ coordinates collected during the FRP procedure were also used to estimate the head flexion-extension angle. A vector from the midpoint of two TMJ markers to the glabellas bone marker was defined. The orientation of this vector with regards to the

horizontal axis of lab-coordinate system was identified as the flexion-extension angle. Standard neutral head position was used to define the flexion-extension of 0°.

4.5.3 Dependent variables

4.5.3.1 FRP parameters: The flexion relaxation response of the neck extensors was quantified using the Flexion-Relaxation Ratio (FRR), onset and offset angles of the silent period (Figure 15), and silent period expansion.

The FRR quantifies the ability of the neck extensor muscles to relax during forward flexion. It is commonly used to distinguish between healthy people and asymptomatic peoples. A diminished FRR was reported in the symptomatic populations with back and neck pain (Watson et al. 1997, Colloca and Hinrichs 2005, Murphy et al. 2010, Maroufi et al. 2012).

FRR is defined as the ratio of the maximum EMG activation in the extension phase (phase 4) to the average EMG activation during full flexion phase (phase 3) (Alschuler et al. 2009, Murphy et al. 2010, Lehman 2012). Equation (4) was used to compute the FRR. A criterion of inverse FRR < 40% was used to identify presence or absence of FRP (Pialasse et al. 2009).

$$FRR = \frac{\text{Maximum EMG in Phase 4}}{\text{Average EMG in Phase 3}} \dots\dots\dots (4)$$

Onset and offset angles are the angles corresponding to the start and end of the myoelectric silence period, respectively. The onset angle corresponds to the flexion angle when the load sharing is transferred from active muscles to passive tissues. The offset angle corresponds to the extension angle where the load sharing is transferred back to the active muscles from passive tissues. Onset and offset angles were determined using the Instantaneous Flexion Relaxation Ratio (IR_i) (Equation 5). The flexion angle corresponding to IR_i < 40% was considered the onset angle, and the extension angle corresponding to IR_i > 40% was defined as the offset angle (Pialasse *et al.* 2009). To standardize across participants, onset and offset angles were expressed as the percentage of maximum flexion.

$$IR_i = \frac{EMG_i}{\text{Maximum EMG in Phase 4}} \dots\dots\dots (5)$$

Where, EMG_i is the instantaneous muscle activity at any time i

Silent period expansion is typically used to quantify the temporal changes in the myoelectric silence of the active tissues in fully flexed posture. To calculate the silent period expansion post-fatigue, the time differences between the onset angle and start of phase 3 (T1) (Figure 15), and the offset angle and end of phase 3 (T2) (Figure 15) was estimated using the following equations:

$$\text{Silent period expansion} = \text{Onset Shift} + \text{Offset Shift} \quad \dots\dots\dots (6)$$

Where,

$$\text{Onset Shift} = T1_{\text{Post Fatigue}} - T1_{\text{Pre Fatigue}} \quad \dots\dots\dots (7)$$

$$\text{Onset Shift} = T2_{\text{Post Fatigue}} - T2_{\text{Pre Fatigue}} \quad \dots\dots\dots (8)$$

In the majority of previous FRP studies, visual inspection was used to determine the start and end points of Phase 3 (Full flexion). To avoid human error and bias, in this research a mathematical criterion was used to identify these points. The start point of Phase 3 was determined as a point corresponding to a flexion angle of two standard deviations below the mean. The mean and standard deviation were calculated using a moving window of 100 points at the starting region of the full flexion (left side of full flexion). The end of Phase 3 was determined in similar manner using a moving window of 100 points at the ending region of the full flexion (right side of full flexion).

4.5.3.2 Muscle reflex parameters: The response of the head-neck system to sudden perturbation was studied by evaluating changes in the stiffness of the cervical spine, reflex gain, reflex amplitude and other temporal parameters that reflect changes in the reflexive behavior of the neck extensors.

4.5.3.3 Stiffness of cervical spine: Stiffness is the rigidity of an object (e.g. spine) necessary to maintain and control its stability. Cervical spine stiffness was identified by relating measured head kinematics (i.e., horizontal motion in the X-direction) to head kinetics (Simoneau et al. 2008, Hodges et al. 2009, Hendershot et al. 2011) (Figure 21) using two separate time windows. The first window starts from the force onset and ends at the EMG onset. Force onset and EMG onset are identified as the peaks exceeding two standard deviations above the mean (mean + 2 SD) of the activity prior to the sudden perturbation (Hendershot et al. 2011). The stiffness

estimated during the first window is provided by the passive tissues and the baseline muscle activity (preload). This is sometime referred to as “intrinsic stiffness” (Moorhouse and Granata 2007, Hendershot et al. 2011). The second time window begins from the EMG onset and ends at the force peak. The intrinsic properties (due to passive tissues and baseline muscle response) as well as the muscle reflexive response provide stiffness during this window and are referred to as “effective stiffness”.

Figure 21: Muscle reflex parameters

In response to sudden perturbations, the head-neck system was modeled as a rigid inverted pendulum attached at the first vertebrae represented by the following a single degree of freedom-second order model which includes stiffness, mass and damping (Gardner-Morse and Stokes 2001, Hendershot et al. 2011):

$$F(t) = m * \ddot{X}(t) + B * \dot{X}(t) + K * X(t) \quad \dots\dots\dots (9)$$

Where,

F(t): is the resultant force vector on the head measured using the load cell in Newton (N).

m: is the effective mass in kg. This will be set equal to the mass of the head, since the upper body including shoulder and trunk will be stabilized during perturbation.

X(t): is the displacement of the center of mass of head expressed in meter, determined using the marker data.

$\dot{X}(t)$: is the linear velocity of the head measured in m/s, calculated as the first derivative of the displacement using the following equation:

$$\dot{X}(t) = \frac{X(t)_{i+1} - X(t)_{i-1}}{2 * \Delta t} \dots\dots\dots (10)$$

Where,

$X(t)_{i+1}$ displacement at time (t)_{i+1}

$X(t)_{i-1}$ displacement at time (t)_{i-1}

Based on the sampling frequency of 100 Hz, $\Delta t = 0.01$ sec.

$\ddot{X}(t)$: is the linear acceleration of head measured in m/sec², calculated as the second derivative of the displacement using the following equation:

$$\ddot{X}(t) = \frac{X(t)_{i+1} + X(t)_{i-1} - 2 \times X(t)_i}{(\Delta t)^2} \dots\dots\dots (11)$$

Where,

B: is the damping coefficient which will be set to zero.

K: is the muscle stiffness measured in Kg/sec².

The stiffness (K) was assumed to be constant after the perturbation during the first and second windows (Hodges et al. 2009) and was calculated by minimizing the error between measured and model-predicted driving forces (Hodges et al. 2009, Hendershot et al. 2011). The head mass was considered to equal 7.2% of participants' whole body mass (Dempster and Gaughran 1967, Clauser et al. 1969). Force data was down sampled from 1000 Hz to 100 Hz using MatLab to match with the motion data sampling rate.

4.5.3.4 Reflex gain: is a measure of the reflex response with respect to trunk velocity (Hendershot et al. 2011). It represents the muscle response magnitude immediately after a disturbance (Rogers 2005). Large magnitudes of reflex gain indicate a large reflex response. Several methods have been used to mathematically quantify the reflex gain. In this study, reflex gain was determined as the peak amplitude of the impulse response function (IRF) using the following equation (Mirbagheri et al. 2000, Granata et al. 2004, Granata et al. 2005, Moorhouse and Granata 2007):

$$h_{Qf}(t) = \frac{Q(t)}{\sum_{\tau} f(\tau)} \quad \dots\dots\dots (12)$$

Where,

$h_{Qf}(t)$: is the IRF

$Q(t)$: is the instantaneous EMG

$\sum f(t)$: is the summation of the force over a short duration of force perturbation (onset to the end of pulse)

Reflex amplitude (Figure 21) is another variable used to quantify the magnitude of muscle reflex as a function of the changes in the muscle myoelectric activity. The reflex amplitude was calculated mathematically as the difference between the peak EMG and average EMG before the perturbations onset (Granata *et al.* 2004, Herrmann *et al.* 2006).

$$\text{Reflex amplitude} = \text{EMG}_{\text{Peak}} - \text{EMG}_{\text{Avg}} \quad \dots\dots\dots (13)$$

4.5.3.5 Temporal Aspects of Muscle Reflex: Three temporal variables; onset delay/latency or reflex delay (OD), time to peak (TTP), and peak to peak time (PTP), were evaluated. Onset latency or reflex delay is quantified as the time between the onset of the force and the onset of the neck muscle electrical activity (Figure 21). Onset times are identified as the points when the signal exceeds a threshold defined by the mean of the baseline activity plus two standard deviations (Granata et al. 2004, Herrmann et al. 2006, Miller et al. 2010). The mean of the baseline muscle activity is calculated using a 500 msec window prior to the perturbation onset. The EMG activity started after 120 msec from the force onset was not included in the analysis and considered as a voluntary response (Matthews 1991, Wilder et al. 1996). Time to peak is

quantified as the time period between the force onset and EMG peak (Herrmann et al. 2006, Sánchez-Zuriaga et al. 2010) (Figure 21). Peak to Peak time is measured as the time period between the force peak and EMG peak (Figure 21).

4.5.4 Recovery

The recovery data was analyzed only for the FRP and SP parameters that were significantly affected by the fatigue. The following equation was used to estimate the overall recovery:

$$\% \text{Recovery} = \frac{\text{Difference between Recovery and Post fatigue}}{\text{Difference between Pre and Post fatigue}} \times 100\% \quad \dots\dots\dots (14)$$

4.5.5 Statistical Analysis

Prior to conducting the statistical analysis the normality of data was tested using the Kolmogorov-Smirnov test and Shapiro-Wilk test. The results showed that the data was normally distributed for all FRP and SP variables (Appendix D & E). The equality of variance (homogeneity of variance) was tested using the Levene's test and was found to be evident (p-value > 0.05) in the majority of FRP and SP parameters (Appendix F & G).

The median frequency and power spectrum data was statistically tested using a mixed ANOVA repeated measures model. Independent variables were participants, gender and fatigue time. The participants were randomly nested in gender. Gender was treated as fixed effect with two levels (male and female). The fatigue time was also treated as fixed effect with two levels (start and end). All the NOVA results are presented in Appendix H.

Statistical analyses were performed to determine the effects of muscular fatigue, gender, side and their interactions on the cervical spine FRP and muscle reflex response parameters. Mixed ANOVA repeated measure test was used to test the differences within and between the independent variables (side, fatigue and gender). Side was considered as within participants fixed effect with two factors; right and left side. Both gender and fatigue were considered between participants effect. Both of them were fixed effect with two factors each (Fatigue: pre post and gender: male and female). All results are presented in Appendix I, J, K & L.

The Recovery data was also analyzed using a mixed ANOVA repeated measure model with two independent variables; gender and time. Gender was treated as a fixed factor with two

levels; male and female. Time was also treated as a fixed factor with four levels: pre-fatigue, post-fatigue, 15 min recovery and 30 min recovery. Significant main and/or interaction effects were further evaluated by conducting comparisons between means using Tukey's Honestly Significant Difference all-pairwise comparison test (Appendix M).

All statistical analyses were conducted using SPSS Statistics software (Manufacturer, Version 21). Significance level was set to 95%.

CHAPTER FIVE: PRELIMINARY STUDIES

In one of the preliminary studies the repeatability of the experimental setup used for the sudden perturbation procedures was tested. A rigid manikin (Rescue Randy 9000) (Figure 22) was used to test the repeatability of force and motion data.

Figure 22: Manikin during the sudden perturbation procedure

The sudden head perturbation procedure was repeated 5 times on two separate days. Within and between days repeatability was assessed by calculating the correlation coefficient (r) and root mean squared error (RMSE) using the following equations:

$$\text{RMSE} = \left[\frac{1}{n} \sum_{i=1}^n (\theta_i - \theta'_i)^2 \right]^{\frac{1}{2}} \quad \dots\dots\dots (14)$$

$$r = \frac{\sum_{i=1}^n (\theta_i - \bar{\theta})(\theta'_i - \bar{\theta}')}{\sqrt{\sum_{i=1}^n (\theta_i - \bar{\theta})^2} \sqrt{\sum_{i=1}^n (\theta'_i - \bar{\theta}')^2}} \quad \dots\dots\dots (15)$$

Where,

θ_i : Averaged force or displacement data for day 1 (between day comparison)

θ'_i : Averaged force or displacement data for day 2 (between day comparison)

n : Number of samples ($n = 100$), and i the sample number ($i = 1, \dots, 100$).

The raw force and displacement data are shown in Figures 23 & 24. Statistical analysis showed no significant between day difference for means and variances of the force and displacement data (Table 7).

Table 7: Statistical analysis between the two days

	P(f)	P(t)	Correlation Coefficient
Force	0.3190	0.8815	0.9994
Displacement	0.1666	0.6103	0.9996

P(f) is the probability for the F-test, while the P(t) is the probability for the t-test

The correlation coefficients for within day comparison ranged between 0.9989 and 0.9999 and 0.9922 to 0.9997, for the force and displacement data, respectively (Table 8 & 9). The corresponding values for between days comparison were 0.9994 and 0.9963 for force and displacement data, respectively. The RMSEs for between days comparison were 0.78% and 3.27% (of peak) for force and displacement data, respectively. An RMSE less than 6% of peak is reported to be acceptable in previous biomechanics studies (Fong et al. 2008). Overall, a high degree of repeatability was observed for force and motion data during sudden perturbation procedure.

In another preliminary study, the effect of fatigue on various FRP parameters was tested. Thirteen male participants were recruited for data collection. Age, weight, and height of the participants were 29.8 ± 7.3 years, 72.8 ± 12.2 kg, and 172.8 ± 5.4 cm, respectively. None of the participant reported any previous problems related to spinal function. Written informed consent was obtained from all participants. The consent form was approved by the local institutional review board. A Bagnoli-16 desktop EMG system (Delsys Inc., Boston, USA) was used to collect the EMG activity of the neck muscles. Head-neck kinematic data was recorded using an eight-camera optical motion-capture system (Vicon Motion Labs, Oxford, UK). As explained in the experimental procedure (section 4.4.1) the participants performed simple cervical flexion-extension task pre- and post-fatigue.

The effect of fatigue on the baseline flexion-relaxation response of the cervical extensors was estimated using flexion-relaxation ratio (FRR), onset and offset angles of silent period, and silent period expansion.

Figure 23: Correlation coefficient and RMSE for force data for the two days

Figure 24: Correlation coefficient and RMSE for displacement data for the two days

Table 8: Correlation Coefficient for the manikin's displacement data

Day1						Day2				
	Trial2	Trial3	Trial4	Trial5		Trial1	Trial2	Trial3	Trial4	Trial5
Day1	Trial1	0.9983	0.9997	0.9996	0.9992	0.9994	0.9990	0.9986	0.9993	0.9976
	Trial2		0.9974	0.9970	0.9992	0.9989	0.9978	0.9965	0.9959	0.9922
	Trial3			0.9989	0.9989	0.9989	0.9976	0.9972	0.9995	0.9993
	Trial4				0.9992	0.9985	0.9976	0.9997	0.9991	0.9976
	Trial5					0.9989	0.9975	0.9997	0.9981	0.9993
Day2	Trial1						0.9976	0.9971	0.9981	0.9993
	Trial2							0.9997	0.9981	0.9993
	Trial3								0.9981	0.9959
	Trial4									0.9993

Table 9: Correlation coefficient for the manikin's force data

Day1						Day2					
	Trial2	Trial3	Trial4	Trial5		Trial1	Trial2	Trial3	Trial4	Trial5	
Day1	Trial1	1.0000	0.9999	0.9999	0.9999		0.9992	0.9993	0.9996	0.9995	0.9992
	Trial2		0.9999	0.9999	0.9999		0.9992	0.9992	0.9996	0.9995	0.9991
	Trial3			0.9998	0.9999		0.9994	0.9993	0.9997	0.9995	0.9991
	Trial4				1.0000		0.9990	0.9991	0.9995	0.9994	0.9992
	Trial5						0.9990	0.9991	0.9995	0.9994	0.9991
Day2	Trial1						0.9999	0.9998	0.9998	0.9995	
	Trial2							0.9999	0.9999	0.9998	
	Trial3								0.9999	0.9997	
	Trial4									0.9999	

For all the dependent variables, the equality of variance and normality test demonstrated that the assumptions of the homoscedasticity and normal distribution were true. One way ANOVA was used and the independent factor fatigue was treated as two levels, pre-fatigue and post-fatigue. Minitab 16 statistical analysis software (Minitab Inc., PA, USA) was used to perform the analysis.

The average time until muscle fatigue was 678 ± 180 sec. No statistical differences were found in FRR, onset angle, offset angle, T1 and T2 (p -value were 0.91, 0.92, 0.91, 0.91, and

0.99, respectively) between right and left neck extensors. Therefore, the data was pooled from both sides for further statistical analysis. The FRP was observed in all participants before and after fatigue. Raw EMG and motion data for one of the participants is shown in Figure 25.

Figure 25: Raw EMG and motion data for one of the participants

The FRR was significantly affected by the fatigue status (p -value < 0.001). The FRR was reduced from 4.03 ± 0.75 to 2.74 ± 0.38 post-fatigue (Figure 26). The onset and offset angles, and T1 and T2 values were significantly affected by the fatigue (Figure 27 & 28). The average onset angle decreased significantly by 13% of maximum flexion post-fatigue (p -value < 0.001). A rather smaller, but significant decrease (2.8% of maximum flexion) in the offset angle was observed post-fatigue (p -value < 0.01). Post-fatigue T1 was significantly higher than pre-fatigue

T1, resulting in an onset shift of 0.55 ± 0.28 sec. The corresponding T2 values also increased significantly, resulting in an offset shift of 0.21 ± 0.09 sec. The post-fatigue expansion of the silent period was 0.76 ± 0.37 sec.

Figure 26: Pre- & post-fatigue FRR. Error bars represent 1 SD. Bars at the end of the brackets are significantly different.

Figure 27: Pre- & post-fatigue average onset and offset angles.

Figure 28: Onset and offset shifts and silent period expansion.

The results of this study showed that neck extensor muscular fatigue modulates the FR parameters by reducing the FRR and increasing the myoelectric silence period. These changes in the FRP parameters suggest that the cervical spine stability may be compromised by the degraded force generating capacity of the fatigued muscles and increased load-sharing by the passive cervical stabilizing structures.

CHAPTER SIX: RESULTS

The objective of this study was to quantify the post-fatigue changes and recovery of the cervical spine's stability. Specifically, the flexion-relaxation phenomenon (FRP) and sudden perturbations (SP) procedures were used to study the variables that influence the stability of the cervical spine. Twenty human participants (10 male and 10 female) were recruited for data collection and the Sorenson protocol was utilized to induce neck muscle fatigue. In the first part of this chapter, muscle activity data during the Sorenson protocol are presented. In the second part of this chapter, post-fatigue changes in the FRP parameters are presented. In the third part of the chapter, post-fatigue changes in the stiffness and reflex response of the neck muscles are presented. In the fourth and final part of this chapter, post-fatigue recovery of FRP and SP parameters is presented. All the values are presented as mean $\pm$ 1 standard deviation. Statistically significant values (p -value ≤ 0.05) in the tables are marked with asterisks (*). Error bars in the figures represent one standard deviation.

6.1 Sorenson protocol and fatigue:

During the Sorenson protocol, the mean endurance time until muscle fatigue was 12.1 ± 5.6 min. Female participants showed a slightly higher (12.9 ± 6.6 min), but statistically insignificant (p -value = 0.535), endurance time compared to male participants (11.3 ± 4.0 min). Please refer to Appendix C for the endurance time data. Neck muscle fatigue during Sorenson protocol was assessed by quantifying changes in the median frequency of the EMG power spectrum (Mannion and Connolly 1997). In addition, changes in the power of different frequency bands within the spectrum (8-16 Hz, 16-32 Hz, 32-63 Hz, 63-125 Hz, 125-250 Hz, and 250-500 Hz) were also assessed.

6.1.1 Median frequency analysis

Statistical analysis indicated no significant difference between the right and left side (Table 10), therefore the median frequency data were pooled from both sides for further analysis.

The fatigue induced during the Sorenson protocol had no effect on the median frequency (p -value = 0.851) (Table 10). However, a significant effect of gender on the median frequency was observed (p -value < 0.001) (Table 10). Males were found to exhibit higher median

frequency than females. No effect of fatigue-gender interaction on the median frequency was observed (Figure 29).

Table 10: Effect of side, fatigue and gender on the median frequency

Median frequency (Hz)	Effect of side		
	Left	Right	<i>P</i> -value
	88.68 ± 18.60	89.44 ± 20.58	0.68
	Effect of fatigue		
	Pre-fatigue	Post-fatigue	<i>P</i> -value
	88.82 ± 18.59	89.28 ± 20.59	0.851
	Effect of gender		
	Male	Female	<i>P</i> -value
	93.16 ± 18.36	84.59 ± 17.79	0.001*

Figure 29: Fatigue-gender interaction effect on frequency power spectrum: (a) median frequency, power of 8-16 Hz, 16-32 Hz and 250-500 Hz frequency bands and (b) power of 32-63 Hz, 63-125 Hz and 125-250 Hz frequency bands.

6.1.2 Power analysis

Similar to the median frequency, the power of different frequency bands from the right side did not differ significantly from the left side, so the data were pooled for further statistical analysis (Table 11). The fatigue had a significant effect on the power of the lower frequency bands. The power of the 8-16 Hz, 16-32 Hz, 32-63 Hz, and 63-125 Hz bands increased with the development of fatigue (all p -values < 0.05) (Table 12). For the other higher frequency bands, a post-fatigue increase in the power was observed without any statistical significance (Table 12).

A significant gender effect was observed on the power of different frequency bands. A higher power was observed for the females than males for the 8-16 Hz, 16-32 Hz, 32-63 Hz, and 63-125 Hz frequency bands (Table 13). No interaction effect of fatigue and gender on the power of different frequency bands was observed (Figure 29).

Table 11: Side effect on the power of different frequency bands

Frequency Band	Right side	Left side	P -value
8-16 Hz	1.01 ± 1.02	0.98 ± 1.51	0.785
16-32 Hz	77.12 ± 114.15	70.04 ± 91.19	0.44
32-63 Hz	281.60 ± 492.57	241.28 ± 312.63	0.313
63-125 Hz	358.50 ± 337.58	439.71 ± 337.43	0.671
125-250 Hz	197.72 ± 229.78	184.56 ± 167.53	0.611
250-500 Hz	49.94 ± 42.99	47.25 ± 31.92	0.512

Table 12: Fatigue effect on the power of different frequency bands

Frequency Band	Pre-fatigue	Post-fatigue	<i>P</i> -value
8-16 Hz	0.75 ± 0.69	1.24 ± 1.66	0.002*
16-32 Hz	55.97 ± 55.00	91.18 ± 133.10	0.005*
32-63 Hz	199.34 ± 205.13	323.53 ± 539.72	0.013*
63-125 Hz	297.90 ± 310.40	398.17 ± 453.86	0.033*
125-250 Hz	170.82 ± 189.93	211.46 ± 209.86	0.129
250-500 Hz	43.76 ± 35.11	53.43 ± 39.88	0.052

Table 13: Gender effect on the power of different frequency bands

Frequency Band	Male	Female	<i>P</i> -value
8-16 Hz	0.68 ± 0.57	1.31 ± 1.68	0.000*
16-32 Hz	46.76 ± 53.16	100.40 ± 130.72	0.000*
32-63 Hz	161.63 ± 179.48	361.25 ± 537.40	0.000*
63-125 Hz	297.84 ± 353.72	398.23 ± 420.96	0.033*
125-250 Hz	209.60 ± 258.16	172.68 ± 116.68	0.168
250-500 Hz	50.59 ± 50.21	46.59 ± 18.48	0.418

6.2 Flexion-relaxation phenomenon (FRP)

Two hundred and forty head-neck flexion extension trials were collected (20 participants, 3 trials per participant, right and left sides, pre- and post-fatigue). The FRP was observed in 234

trials, and was found to be absent post-fatigue in two female participants.

6.2.1 Side effect

Statistically, the FRP parameters were found to be not different between the left and right sides (Table 14). Consequently, the data was pooled from both sides for further statistical analysis.

Table 14: Side effect on FRP parameters

FRP parameters	Right side	Left side	P-value
FRR	4.09 ± 1.07	4.12 ± 1.04	0.564
Onset angle (% full flexion)	73.90 ± 7.39	73.80 ± 6.94	0.668
Offset angle (% full flexion)	94.70 ± 3.08	94.40 ± 3.45	0.157
T1 (centiseconds)	126.09 ± 40.38	126.82 ± 40.57	0.381
T2 (centiseconds)	29.63 ± 11.45	29.38 ± 11.90	0.598
Expansion (centiseconds)	155.72 ± 48.75	156.19 ± 49.37	0.589

6.2.2 Gender effect

The effect of gender on the FRR was statistically significant. Females showed higher FRR than males (Table 15). For all other FRR parameters, the effect of gender was statistically insignificant (Table 15).

6.2.3 Fatigue effect

The effect of fatigue on the FRP parameters was statistically significant (Table 12). The FRR was reduced significantly from 4.88 ± 0.81 pre-fatigue to 3.33 ± 0.57 post-fatigue (Table 16). Smaller onset and offset angles were observed post-fatigue. The onset angle decreased by about 16% and the offset angle was decreased by about 5%. The time differences between the onset angle and start of phase 2 (T1), and the offset angle and end of phase 2 (T2) increased significantly post-fatigue. The T1 increased by about 71.4% and T2 increased by about 98.3%.

These changes in the T1 and T2 caused the silent period to expand by about 86 centiseconds, This increase is equivalent to 17.2% (86/500), where 500 centiseconds is the average length of the silent period for all participants (Table 16).

Table 15: Gender effect on FRP parameters

FRP parameters	Male	Female	<i>P</i>-value
FRR	3.89 ± 0.92	4.32 ± 1.12	0.05*
Onset angle (% full flexion)	74.50 ± 6.89	73.20 ± 7.51	0.223
Offset angle (% full flexion)	94.40 ± 3.00	94.70 ± 3.41	0.682
T1 (centiseconds)	122.05 ± 34.08	130.86 ± 46.33	0.226
T2 (centiseconds)	30.08 ± 12.32	28.92 ± 11.08	0.560
Expansion (centiseconds)	152.13 ± 44.32	159.78 ± 54.14	0.300

Table 16: Fatigue effect on FRP parameters

FRP parameters	Pre-fatigue	Post-fatigue	<i>P</i>-value
FRR	4.88 ± 0.81	3.33 ± 0.57	< 0.001*
Onset angle (% full flexion)	80.20 ± 2.16	67.6 ± 4.07	< 0.001*
Offset angle (% full flexion)	96.90 ± 1.34	92.2 ± 2.64	< 0.001*
T1 (centiseconds)	93.18 ± 14.44	159.73 ± 28.46	< 0.001*
T2 (centiseconds)	19.78 ± 3.16	39.23 ± 8.13	< 0.001*
Expansion (centiseconds)	112.96 ± 14.81	198.96 ± 28.55	< 0.001*

6.2.4 Fatigue-gender interaction effect

The fatigue-gender interaction effect was statistically insignificant for all FRP parameters (p -value > 0.05) (Figure 30).

Figure 30: Fatigue-gender interaction effect on FRP parameters: (a) FRR, (b) onset and offset angles, and (c) temporal variables.

6.3 SP results

The effect of fatigue on parameters related to the muscle reflex response was investigated using the SP procedure. These parameters are classified as temporal and magnitude-related. The temporal parameters include onset delay (OD), time to peak (TTP), the time difference between the force peak and muscle activity peak, i.e., peak to peak time (PTP). The amplitude-related parameters include reflex gain (RG) and reflex amplitude (RA).

6.3.1 Side effect

The statistical analysis showed no significant difference between the right and left side for all SP parameters (Table 17). Accordingly, the data were pooled from both sides for further statistical analysis.

Table 17: Side effect on SP parameters

SP parameters	Right side	Left side	P-value
OD (msec)	110.32 ± 31.39	110.19 ± 31.33	0.835
TTP (msec)	277.85 ± 67.71	278.77 ± 63.27	0.551
PTP (msec)	132.91 ± 63.31	134.66 ± 61.25	0.284
RG ($\times 10^{-3}$, N ⁻¹)	2.09 ± 1.04	2.19 ± 1.07	0.085
RA	2.11 ± 0.98	2.23 ± 1.06	0.110

6.3.2 Gender effect

The gender had no significant effect on the muscle reflex temporal parameters (OD, TTP and PTP), but it had a significant effect on the muscle reflex magnitude-related parameters (RG and RA) (Table 18). The RG values among females were about 65% higher than males (p -value = 0.001). The RA values were about 30% higher in females compared to males (p -value = 0.001) (Table 18).

Table 18: Gender effect on SP parameters

SP parameters	Male	Female	P-value
OD (msec)	115.40 ± 35.33	105.11 ± 31.33	0.219
TTP (msec)	274.16 ± 62.20	282.46 ± 69.67	0.571
PTP (msec)	130.65 ± 59.37	137.01 ± 66.05	0.648
RG ($\times 10^{-3}$, N ⁻¹)	1.61 ± 0.69	2.65 ± 1.03	0.001*
RA	1.70 ± 0.70	2.23 ± 1.06	0.001*

6.3.3 Fatigue effect

On the other hand, fatigue had a significant effect on the muscle reflex temporal parameters, but had no significant effect on the muscle reflex magnitude-related parameters (Table 19).

Table 19: Fatigue effect on SP parameters

SP parameters	Pre-fatigue	Post-fatigue	<i>P</i> -value
OD (msec)	92.81 ± 21.06	127.07 ± 30.45	< 0.001*
TTP (msec)	231.08 ± 39.55	325.54 ± 49.99	< 0.001*
PTP (msec)	89.36 ± 36.40	178.22 ± 49.28	< 0.001*
RG ($\times 10^{-3}$, N ⁻¹)	2.40 ± 1.17	1.88 ± 0.84	0.069
RA	2.43 ± 1.04	1.91 ± 0.89	0.067

Muscular fatigue significantly increased the OD, TTP and PTP values by 36.9% (*p*-value = 0.001), 40.9% (*p*-value = 0.001), 99.4% (*p*-value = 0.001), respectively. The fatigue also reduced the RG and RA values by about 22%. But this change was statistically not significant (Table 19).

6.3.4 Fatigue-gender interaction effect

The interaction effect of fatigue and gender on the muscle reflex temporal and magnitude-related parameters was not significant (all *p*-value > 0.05) (Figure 31). The temporal parameters (OD, TTP & PTP) were consistently higher post-fatigue than pre-fatigue for both the genders. Females exhibited higher values for magnitude-related parameters than males pre and post-fatigue (Table 18).

Figure 31: Fatigue-gender interaction effect on FRP parameters: (a) muscle reflex temporal parameters; (b) muscle reflex magnitude-related parameters.

6.3.5 Muscle stiffness

Using the data recorded during sudden perturbations, the stiffness of the cervical spine was estimated pre- and post-fatigue. Higher stiffness was observed for males than females, however, the difference was statistically not significant (p -value > 0.05) (Table 20). The effect of fatigue on the stiffness was statistically significant and decreased for both the intrinsic and effective stiffness by about 15.3% and 22.6%, respectively, post-fatigue (p -value = 0.001) (Table 20). The fatigue-gender interaction effect on the intrinsic and effective stiffness was statistically insignificant (p -value = 0.813 and 0.580, respectively) (Figure 32).

Table 20: Gender and fatigue effect on stiffness

	Effect of gender		
	Male	Female	<i>P</i> -value
Intrinsic stiffness (Kg/sec ²)	910.68 ± 115.62	891.38 ± 117.47	0.503
Effective stiffness (Kg/sec ²)	1270.77 ± 207.03	1220.40 ± 198.33	0.204
	Effect of fatigue		
	Pre-fatigue	Post-fatigue	<i>P</i> -value
Intrinsic stiffness (Kg/sec ²)	975.75 ± 85.87	826.31 ± 90.76	0.001*
Effective stiffness (Kg/sec ²)	1404.64 ± 122.31	1086.53 ± 123.73	0.001*

Figure 32: Fatigue-gender interaction effect on the stiffness

6.4 Recovery data

Post-fatigue recovery of the FRP and SP parameters was assessed after 15, 30, 45, and 60 minutes. At each instance during the recovery period, head flexion extension and SP procedures were repeated and the data was analyzed separately for each period to monitor the recovery process.

6.4.1 FRP recovery data

All the FRP parameters were significantly affected by the fatigue and recovery process (all p -value < 0.05) (Figure 33 & 34). For all of the FRP parameters, the result of post hoc pairwise comparison showed that the values obtained at the end of the 15, 30, 45, and 60 minutes rest periods were significantly different from the post-fatigue values. Statistically, no difference was found between the values obtained pre-fatigue, and after 15, 30, 45, and 60 minutes of recovery (Figure 33 & 34). Post hoc pairwise comparison analysis is available in Table 52 in Appendix M.

Overall recovery (percent recovery) data is presented in Table 21. Close to 90% recovery was observed for the FRR, T1, T2 and silent period expansion after 15 minutes of recovery. Close to 80% recovery was observed for the onset and offset angles (Table 21). After 30 min of rest, FRR, T1, T2 and silent period expansion recovered up to 95% and the onset and offset angles recovered close to 90% (Table 21). After 45 min of rest, all the FRP parameters showed a 100% recovery.

Gender had no effect on the FRP parameters (all p -value > 0.05) during the fatigue and recovery process (Table 22). The interaction effect of fatigue and gender on the FRP parameters during fatigue and recovery process was also statistically not significant.

Figure 33: Post hoc pairwise comparison for the FRR, onset and offset angles

Figure 34: Post hoc pairwise comparison for FRP temporal parameters

Table 21: FRP parameters recovery data

FRP parameter	15 min % Recovery	30 min % Recovery	45 min % Recovery	60 min % Recovery
FRR	94.48 ± 7.98	98.79 ± 3.73	100.38 ± 1.08	100.57 ± 1.04
Onset angle (% full flexion)	78.70 ± 9.60	89.41 ± 8.71	100.06 ± 1.58	100.50 ± 1.61
Offset angle (% full flexion)	83.59 ± 11.31	91.02 ± 10.11	100.30 ± 1.95	101.61 ± 2.40
T1 (centiseconds)	91.05 ± 9.19	96.86 ± 3.89	100.08 ± 0.55	100.30 ± 0.51
T2 (centiseconds)	90.13 ± 8.68	95.60 ± 4.53	100.03 ± 1.36	101.04 ± 0.88
Expansion (centiseconds)	90.95 ± 7.62	96.37 ± 5.16	100.02 ± 0.58	100.43 ± 0.48

Table 22: Gender effect on the FRP parameters recovery (Data represented as % Recovery)

FRP parameters	Male	Female	<i>P</i> -value
FRR	98.17 ± 5.57	98.95 ± 4.46	0.455
Onset angle (% full flexion)	93.21 ± 9.86	91.13 ± 12.22	0.153
Offset angle (% full flexion)	95.04 ± 9.68	93.22 ± 11.47	0.302
T1 (centiseconds)	97.07 ± 5.93	97.09 ± 6.64	1.000
T2 (centiseconds)	98.01 ± 3.66	95.96 ± 6.87	0.171
Expansion (centiseconds)	97.3 ± 5.19	97.09 ± 6.63	0.845

6.4.2 SP recovery data

The SP temporal parameters (OD, TTP, and PTP) and stiffness were significantly affected by the fatigue and recovery process (all p -value < 0.05). For all of these parameters, the result of post hoc pairwise comparison showed that the values obtained after 15, 30, 45, and 60 minute of rest periods were significantly different from the post-fatigue values (Figure 35 & 36).

Figure 35: Post hoc pairwise comparison for the OD & TTP

Figure 36: Post hoc pairwise comparison for the PTP & stiffness

Statistically, no significant difference was found between the values obtained pre-fatigue, after 15, 30, 45, and 60 minutes of recovery (Figure 35 & 36). Post hoc pairwise comparison analysis is available in Table 57 in Appendix M.

Recovery of about 86% to 91% was observed after 15 minutes of rest. After 30 minutes of rest recovery of about 93% to 97% was observed (Table 23). Close to 100% recovery was observed after 45 minutes of rest for all SP parameters. Similar to FRP parameters, gender had no effect on the investigated SP parameters (all p -value > 0.05) during the fatigue and recovery process (Table 24). The interaction effect of fatigue and gender on the SP parameters during fatigue and recovery process was also statistically not significant.

Table 23: SP recovery data

SP parameter	15 min % Recovery	30 min % Recovery	45 min % Recovery	60 min % Recovery
OD (msec)	87.95 ± 8.31	95.43 ± 4.23	99.11 ± 1.24	100.37 ± 1.00
TTP (msec)	88.06 ± 7.78	93.83 ± 5.16	98.70 ± 0.87	100.77 ± 1.00
PTP (msec)	91.69 ± 8.26	96.67 ± 3.85	99.79 ± 0.40	100.97 ± 0.62
Stiffness (Kg/sec ²)	86.44 ± 4.32	92.98 ± 4.27	99.04 ± 0.77	100.71 ± 1.21

Table 24: Gender effect on SP parameters recovery (Data represented as % Recovery)

SP parameters	Male	Female	P -value
OD (msec)	96.61 ± 5.54	94.81 ± 7.69	0.084
TTP (msec)	95.24 ± 6.73	95.44 ± 6.87	0.853
PTP (msec)	97.46 ± 6.36	97.09 ± 6.19	0.724
Stiffness (Kg/sec ²)	94.52 ± 7.09	95.06 ± 5.77	0.443

CHAPTER SEVEN: DISCUSSION AND CONCLUSIONS

This study was designed to quantify the effect of muscular fatigue on the stability of cervical spine. It is the first study to explore several variables that are traditionally related to the stability of the spine and determine those that are the most significant for the cervical spine. Understanding the impact of muscular fatigue on these parameters is expected to improve our overall understanding of the patho-mechanism of fatigue induced cervical spine MSDs. Consequently, this can provide valuable insight into understanding and quantifying the risk factors for cervical spine MSDs, and opens the door for possible ergonomic interventions to eliminate these MSDs.

Findings of the current study indicate that the muscular fatigue alter the stability of cervical spine. The discussion of the findings is divided into six major sections. In the first section, the effect of muscular fatigue and gender on the FRP parameters is discussed. The second section focuses on the effects of muscular fatigue and gender on the SP parameters. The third section focuses on the recovery behavior of the FRP and SP parameters. In the fourth section, limitations of the current study are presented. Some practical implications are presented in the fifth section, and finally conclusions are summarized in the sixth section.

7.2 Flexion-relaxation phenomenon

7.2.1 Effect of muscular fatigue

Results showed that the muscular fatigue reduced FRR from 4.88 ± 0.81 to 3.33 ± 0.57 . This finding supports our hypothesis and is congruent with the results of our preliminary studies (Nimbarte et al. 2013d, Nimbarte et al. 2013e) and a number of existing studies (Watson et al. 1997, Murphy et al. 2010, Lee et al. 2011b, Maroufi et al. 2012). The post-fatigue reduction in the FRR was mainly due to the increased activation of neck extensors during the relaxation (third) phase. The activation level of the neck muscles increased by about 20% after fatigue. Bonato et al. (2003) and Clark et al. (2003) attributed such increase in the EMG amplitude to the reduced force-generation capacity of the fatigued muscles. Under fatigued condition, changes in the concentrations of calcium ions (Ca^{2+}) and lactic acid negatively impact muscle fiber excitation-contraction coupling (Kurebayashi and Ogawa 2001, Allen 2004). As a consequence,

increased motor unit firing rate is required to maintain similar force exertion levels especially during isometric exertions (Vukova et al. 2008). The increased muscular activation during relaxation phase could be due to the augmented firing rate of the motor units that isometrically counteract the effect of gravity on the head.

Lower FRR for symptomatic people compared to normal symptom free individuals was reported in a few studies (Watson et al. 1997, Gupta 2001, Murphy et al. 2010, Maroufi et al. 2012). These studies reported a FRR of around 4 for cervical and lumbar spines among the normal people. In the people with pain symptoms, a reduced FRR of 2 was reported. We believe that the mechanism that leads to fatigue induced reduction in FRR is very different than the reduced FRR observed among symptomatic people. Among the symptomatic individuals, spinal instability caused by the damaged passive tissues has been proposed to produce persistent activation of the extensor muscles during the relaxation period to cause the reduction in FRR. Among the normal symptom free individuals, results of this study indicate an early shift in the loading sharing to the passive tissues as well as increased activation by the active tissues during the silence period causing the reduction in the FRR. Altogether, a relatively high muscular demand is expected among the symptomatic individuals to maintain satisfactory functional status. This may lead to early onset of fatigue, further increasing the demands on the already fatigued muscles and increasing the risk of injury.

The data also support our hypothesis regarding the effect of fatigue on the onset and offset angles of the silent period. Both onset and offset angles were significantly decreased due to muscle fatigue from $80.20 \pm 2.16\%$ to $67.6 \pm 4.07\%$ and $96.90 \pm 1.34\%$ to $92.2 \pm 2.64\%$, respectively. These results are in agreement with the findings reported in our preliminary study and the findings of Descarreaux et al. (2008). Descarreaux et al. (2008) studied the effect of fatigue on the lumbar spine FRP parameters. They reported that the onset and offset angles were reduced by muscular fatigue from 80% to 74% and 93% to 85%, respectively. These findings are consistent with our results. Olson et al. (2004) also reported similar trends in the onset and offset angles due to muscular fatigue generated by prolonged cyclic lumbar flexion. Cyclic flexion generates passive tissue creep in addition to the muscular fatigue and makes the interpretation of the data challenging. In the current study and the studies performed by Descarreaux et al., the Sorenson protocol was used to independently generate fatigue in the active tissues to investigate FRP. This protocol was also proven to be very effective in generating muscular fatigue without

developing passive tissues creep as in several other lumbar spine studies (Koumantakis et al. 2001, da Silva Jr et al. 2005). In the current study, the spectral analysis of the muscle activity data during the Sorenson protocol showed an increase in the power of the lower frequency bands indicating development of muscle fatigue (Dolan et al. 1995, Mannion et al. 1996, Sparto et al. 1997, Cardozo et al. 2011).

A post-fatigue reduction in the onset and offset angles produced an expansion of silence period. In the current study, the expansion of silence period was estimated as the sum of onset and offset shifts. The lower onset angles observed after the fatigue increased the onset shift causing silence period to begin at an earlier instance compared to before fatigue condition. On the other hand, lower offset angle increased the offset shift resulting in delayed cessation of silence period post-fatigue. The early onset of the silence period is an indicator that the fatigued cervical extensors were unable to maintain the forces required to stabilize the cervical spine and consequently shifted the load sharing to the passive tissues much before the deep flexion. The delayed cessation of the silence period shows that the fatigued cervical extensors must have relied upon the deep cervical muscles to generate moment in the early extension (fourth) phase.

The onset shift was almost three fold the offset shift indicating a more pronounced contribution by the passive viscoelastic tissues than deep muscles in stabilizing cervical spine under fatigued condition. For lumbar spine it has been proposed that the deep back muscles initiate trunk extension in the fatigued condition whereas the superficial muscles initiate trunk extension in the non-fatigued condition (Descarreaux et al. 2008). A very small offset shift observed in this study does not seem to fully support this notion for the cervical spine. On the other hand, it is also likely that the Sorenson protocol used in this study may have fatigued the deep muscles to some extent (perhaps lesser than superficial muscles) affecting their ability to generate the extension moment producing a narrow offset shift. Intramuscular recording would be required to further confirm deep and superficial muscle synergies pre- and post-fatigue.

The onset and offset angles, especially for pre-fatigue condition, reported in this study were slightly higher than the results reported in the earlier FRP studies (Pialasse et al. 2009, Pialasse et al. 2010, Maroufi et al. 2012). We reported 80.2% and 96.9% for pre-fatigue onset and offset angles, respectively, compared to 73-76% and 91-92% reported in earlier FRP studies. The difference could be due to the variability in the criteria used to identify these angles.

Most of the previous studies used visual inspection, while a quantitative method ($IR_i < 40\%$, Mean (2 SD)) was used in this study to define these angles.

Other studies investigating modulation of spinal FRP due to static flexion (Solomonow et al. 2003a, Youssef et al. 2008, Shin et al. 2009), cyclic flexion (Dickey et al. 2003, Shin and D'Souza 2010), and spinal shrinkage (Shan et al. 2012) reported shortening of the silence period. Unlike the current study, the exposures used in most of these studies produce creep, negatively impacting the force generation ability of the passive tissues. This may increase the contribution required by the neck muscles to maintain stability, resulting in delayed shift in the load sharing to the passive tissues and consequently a diminished silence period.

7.2.2 Effect of gender

The FRR was the only FRP parameter that was significantly affected by the gender. Females exhibited higher FRR than males. The activation level in females during silence period was about 36% higher than males. During the extension phase the corresponding difference was about 58%. The relatively higher activation during the extension phase attributed to the higher FRR among female than male. We believe that this observed gender difference could be due to the differences in the muscle fiber composition. In general, females have higher proportions of type I fibers (slow twitch) compared to males (Esbjörnsson-Liljedahl et al. 1999, Maher et al. 2009). These fibers are fatigue resistant which is evident from the longer endurance time observed for females than males in the current study. In previous studies, Descarreaux et al. (2008) reported no significant difference between both genders for the lumbar spine FRP parameters (FRR, onset and offset angles). Also, no significant gender differences for the FRP parameters (onset and offset angles) were reported by Dickey et al. (2003) ($n = 30$ with 50% females) when investigated the effect of cyclic flexion on the lumbar spine FRP. In comparison, Solomonow et al. (2003a) reported significant gender differences for the onset and offset angles when studied the effect of 10 minutes of static flexion on the FRP parameters. Females were observed to report higher onset and offset angles than males. The authors attributed this difference to the possibility of females developing more creep in passive tissues than males. Unfortunately, the authors did not study the effect of cyclic flexion on the FRR to make any comparison with the current study.

7.3 Sudden perturbation

7.3.1 Effect of muscular fatigue

The SP protocol used in this study provides an ideal setting to investigate post-fatigue changes in the neuromuscular control strategies of the cervical spine. When exposed to sudden and unexpected perturbations, the cervical spine is stabilized by a quick (reflex) response by the neck muscles. The timing and intensity of the reflex response is crucial to attain sufficient stability and minimize the risk of injury. In the current study the effect of fatigue on three temporal and two magnitude (intensity)-related parameters was investigated.

7.3.1.1 SP temporal parameters

The SP temporal parameters investigated in this study measures the timing of: (1) initiation of the muscles response to an external modulator/force (onset delay); (2) muscle generating sufficient force to counterbalance the external force (time to peak and peak to peak).

The initiation of muscle response (onset delay) was delayed post-fatigue and the time to peak and peak to peak numbers also increased post-fatigue. Hassanlouei et al. (2012) reported similar findings for the reflex response by the knee extensors and flexors due to fatigue. Moore et al. (2002) also showed an increase in the patellar tendon reflex onset delay and time to peak for female participants due to the fatigue.

For lumbar spine, previous SP studies report conflicting findings. Some studies have reported no effect of fatigue on the SP temporal parameters (Herrmann et al. 2006, Sánchez-Zuriaga et al. 2010). Other studies have reported an early onset of the reflex response (Allison and Henry 2002, Dupeyron et al. 2010). The studies evaluating creep reported delayed reflex response due to the exposure to prolonged trunk flexion (McGill and Brown 1992, Rogers and Granata 2006, Shin and Mirka 2007).

One of the possible explanations for the differences in the results of our study and the aforementioned lumbar spine studies is the experimental protocol used to induce muscular fatigue. In the current study, the Sorenson protocol was used to generate fatigue. Herrmann et al. (2006) used dynamic back extensions to induce fatigue. Allison and Henry (2002) asked their participants to exert a continuous force (equivalent to 60% MVC) using lumbar spine against a padded rigid support until the participants could not maintain force above a threshold of 35%

MVC. The fatigue protocol used by Dupeyron et al. (2010) consisted of multiple sets of isometric submaximal trunk exertions such that the participants maximal isometric back extension force reduced to 60% of their unfatigued MVC force. Most of these protocols may not independently produce muscle fatigue. Rather, the protocols using dynamic trunk extensions may very well induce passive tissues elongation resulting in the development of creep. The deformation of passive tissue due to creep may deteriorate their ability to stabilize the spine and may require the muscles to respond much earlier than before to stabilize the spine.

For symptomatic people longer onset latencies (delay) of muscle reflexes have been reported after sudden perturbations compared to normal symptom free individuals (Wilder et al. 1996, Radebold et al. 2000, Radebold et al. 2001, Cholewicki et al. 2005). If the symptoms are due to active tissue weakness then these trends resemble with the post-fatigue trends observed in the current study. If the symptoms are due to damaged passive tissues then these trends conflict with the findings/interpretation of the FRP study. Based on the observations made for the FRP parameters, damaged passive tissues may increase the contribution required by the neck muscles to maintain stability resulting in an early initiation of the muscle response or reduced onset latencies (delay) of muscle reflexes. For lumbar spine, however, longer onset latencies were reported post-creep. Currently, no study has looked at the effect of passive tissue deformation on the stability of cervical spine. The results observed for the lumbar spine may or may not be valid for the cervical spine. Lumbar spine is a much rigid structure compared to cervical spine with a smaller range of motion and therefore the load sharing mechanism between the active and passive tissues may follow a different trend.

7.3.1.2 Relationship between TTP and PTP

In this study a new parameter, PTP, was investigated to explore its possible relationship with the TTP. A linear relationship was observed between the two parameters with a correlation of about 0.97 (Figure 37), indicating a high degree of association. This suggests that PTP can be used interchangeably with TTP. Although both parameters essentially provide the same information, i.e., time needed for the muscle to generate sufficient force to balance the external demand, we believe that the computation method for PTP is straightforward, reliable and less prone to variability. The PTP is estimated as the difference between the peaks of force and EMG

data which are very easy to locate. The TTP on the other hand use a moving window with a criterion of (mean + 2 SD) to determine the force onset points.

Figure 37: Relationship between TTP and PPT

7.3.1.3 Reflex gain and reflex amplitude

A non-significant decrease in the reflex gain and reflex amplitude was observed due to the fatigue. This finding rejects our hypothesis that fatigue will significantly reduce the reflex gain and reflex amplitude. Similar types of previous studies have reported conflicting findings. In agreement with our results, Moore et al. (2002) reported that fatigue did not affect the knee reflex amplitude for the males and insignificantly reduced it for females. On the other hand, Hassanlouei et al. (2012) reported that the knee muscular fatigue significantly reduced the muscle activity amplitude. Similarly, Zhang and Rymer (2001b) showed a decrease in the elbow extensor muscle reflex gain due to the fatigue. For lumbar spine, increase in the lumbar spine reflex gain and reflex amplitude was reported due to the muscular fatigue (Allison and Henry 2002, Herrmann et al. 2006, Dupeyron et al. 2010, Sánchez-Zuriaga et al. 2010). Granata et al. (2007) reported a decrease in the reflex gain due to torso flexion (4 different angles; 0°, 30°, 60° and 90°) at two different extortion conditions (30% and 50% of the participants maximum voluntary exertion). Hendershot et al. (2011) reported an increase in the reflex gain due to prolonged trunk flexion (three angles; 33, 66, and 100% of full flexion) at two different durations (2 and 16 minutes). Interestingly, Granata et al. (2005) only reported an increase in the females' reflex gain, and no change was reported for males when investigated the effect of 15 minutes of

static flexion on the paraspinal reflex behavior. As discussed in the 6.2.1.1 section, the fatigue protocol (cyclic vs static) and the morphological and physiological difference between the lumbar and cervical spine could be the possible explanation for the differences between our results and previous lumbar spine studies.

7.3.1.4 Stiffness

Stiffness plays an important role in the stability of the spine and is maintained by the active and passive components of the neuromuscular system. It was hypothesized that the muscle fatigue would decrease the stiffness due to the reduction in the active support. The data supported this hypothesis and is in agreement with the muscle reflex response data. The muscle reflex behavior observed in the current study clearly shows a post-fatigue inhibition in the muscle force generation ability. The baseline muscle activation was reduced by about 10% post-fatigue. Zhang and Rymer (2001b) studied the effect of fatigue on the human elbow extensor muscle reflex response and also reported a reduction in the elbow extensor muscles stiffness. The reduction in the stiffness was explained as the result of the reduction in the force generating capacity of fatigued muscles. This is in agreement with our findings.

In a previous study by Hendershot et al. (2011) the effect of prolonged trunk flexion on the muscle reflex behavior and spinal stiffness was studied. A decrease in the intrinsic stiffness accompanied by an increase in the reflex gain was reported in this study. The authors argued that the reduction in the passive support due to the use of sustained flexed posture was compensated by the increased reflex gain to maintain mechanical equilibrium and stability of the lumbar spine. Following this notion a compensatory adaptation of the passive components of neuromuscular system is expected after the muscle fatigue for the cervical spine to maintain its stability. An early shifting of load sharing to the passive tissue after the muscle fatigue observed during FRP may further support this notion.

7.3.2 Effect of gender

Results indicated that the gender had no significant effect on the SP temporal parameters and stiffness, but had a significant effect on the reflex gain and reflex amplitude. Despite the statistical insignificance females found to exhibit shorter reflex delay than males indicating a faster reflex response. Previously Granata et al. (2005) and Miller et al. (2010) reported similar trend of lower reflex latency for female (shorter reflex latency) compared to male for lumbar

spine. Higher trunk flexion velocity for females than males due to smaller trunk mass was identified as the possible explanation for the lower reflex latency. One possible explanation for not seeing significant difference between the two genders is the use of the preload. Preloads are reported to stabilize/initialize the spine and make the reflex response shorter and could possibly mask any gender difference (Lee et al. 2007).

A significantly higher reflex gain and reflex amplitude were observed for females than males. These variables are estimated during a small window of the force data followed by the weight drop during sudden perturbation. For females, due to their relatively smaller mass, higher head velocity is expected compared to males. This higher velocity would also require higher muscle peak force resulting in higher reflex amplitude in females than males. Higher velocity can reduce the window size of the force data further reducing the value of the denominator (summation of force) used in the estimation of the reflex gain. Increased peak force and reduced force summation produce higher reflex gain for female than males. The reflex gain and reflex amplitude behavior observed in this study for different genders is consistent with results reported by Granata et al. (2005) and Granata and Rogers (2007). Authors indicated that females had a higher reflex gain than males. They explained this as the result of the contribution of trunk velocity dependent on the trunk mass. Hence, females exhibited higher velocities than males due to their smaller trunk mass and subsequently generated higher reflex gain.

No significant effect of gender on the stiffness was observed in this study. This is congruent with a number of existing lumbar spine studies (McConnell et al. 1995, Granata et al. 2004, Granata et al. 2005, Rogers and Granata 2006, Granata and Rogers 2007, Shin and Mirka 2007, Hendershot et al. 2011).

7.4 Recovery

This is the first study to look at the post-fatigue recovery of the stability of cervical spine. The existing literature on the recovery behavior is dominated by low back studies looking at the recovery after exposure to different loading conditions (cyclic, cumulative, static, etc.). The understanding of the recovery process after exposure to different types of exertions is necessary to quantify appropriate work/rest cycles and to identify suitable control measures.

The parameters that showed significant change after the fatigue were analyzed to study the post-fatigue recovery of the cervical spine. Accordingly, all FRP parameters, SP temporal

parameters and muscle stiffness were assessed after rest periods of 15 and 30 minutes. On average, the neuromuscular system recovered by 88% within the first 15 minutes of rest. During the second recovery period of 15 minutes, the recovery process was rather slow and ranged between 5 to 11%. Close to 100% recovery was observed after 45 minutes of rest (i.e., after third recovery period of 15 minutes). Similar findings were reported in the previous lumbar spine studies. Hendershot et al. (2011) reported a fast recovery (about 90%) during the early stage of recovery (about 50% of recovery time) when studied the effect of static flexion (full flexion of lumbar spine) at two different durations (2 and 16 min). Jackson et al. (2001) reported that after 20 minutes of static lumbar flexion, most of the recovery took place within the first 10 minutes of rest and only an additional 11% improvement was observed during the rest of 7 hours. Shin and Kin (2007) investigated the effect of lumbar spine fatigue using the median frequency and reported that 90% of participants showed full recovery in 5 minutes rest after the exposure to 10 min of lumbar spine full flexion followed by a 10 minutes of upright standing.

A quick recovery during the early stage followed by a slow recovery seems to indicate that the recovery process of the cervical spine stability follows an exponential model. A number of previous studies have proposed similar recovery behavior for lumbar viscoelastic laxity and reflexive muscular activity (Gedalia et al. 1999, Solomonow et al. 2000, Jackson et al. 2001, Hatipkarasulu 2002, Solomonow et al. 2003b, Lu et al. 2004). Unfortunately, the experimental procedure used in this study did not allow us to collect more data points within the first 15 minutes and therefore hinder our ability to fit an actual mathematical model. To perform the FRP and SP procedures consecutively, 10 to 12 minutes of experimental preparation time was required. Thus, 15 minutes was the most convenient (minimum possible) choice of rest time in this study.

Based on the recovery process, some recommendations could be made about the rest period calculations. Although 100% recovery was not seen after 15 minutes of rest, statistically no difference was found in the stability of cervical spine pre-fatigue and after 15 minutes of rest. The average exertion time (i.e. endurance time) was 12.1 minutes. This may suggest that the recovery process took approximately the same duration as exposure. But the extreme posture used in the current study to induce fatigue is different than traditional workplace exertions and may have induced fatigue at a much faster rate. Keeping this in mind, it can be postulated that the rest period due to the exertions that are demanding to the cervical spine could be smaller than

the duration of the exertions. For the lumbar spine, Hendershot et al. (2011) stated that the recovery of the muscle reflex response following the prolonged trunk flexion required approximately the same duration as exposure. A few other lumbar spine studies, however, showed that the recovery process took longer than the duration of exposure (McGill and Brown 1992, Jackson et al. 2001, Rogers and Granata 2006, Shin and Mirka 2007).

Interestingly, the onset and offset angles showed a lower recovery compared to the FRR. Onset angle, offset angle and FRR recovered by 79%, 84%, 94%, respectively, during the first 15 minutes of rest, and recovered by 89%, 91%, and 99%, respectively, during the next 15 minutes of rest. The slow recovery of the onset and offset angles indicates that the passive tissues were maintaining the load sharing longer to ensure the full recovery of the fatigued neck muscles; even though the FRR shows good recovery and restoration of normal muscle functionality. This was not studied or reported in the previous literature. We believe that this is a safety mechanism used by the neuromuscular system to ensure sufficient stability and preparedness against unexpected force demand. The recovery process was not affected by the gender. The literature on the relationship between the post-fatigue recovery and gender is limited. Only one study by Hendershot et al. (2011) reported that females recovered faster than males in regard to stiffness, but no gender differences were observed in regard to reflex gain. This study looked at the effect of flexed trunk posture on the reflexive behavior of the lumbar spine. We suspect that the longer rest periods used in the current study may have dampened the effect of gender on the recovery process. Gender difference could've been existed within the resting period, but we were not able to detect this difference due to the length of this period.

7.5 Limitations and future research

There are several limitations of the current study that need to be acknowledged and should be considered while interpreting and translating findings of this study to real workplace situations. First, the Sorenson protocol was used as a standardized procedure to induce neck muscle fatigue. Fatigue at workplaces may be generated due to different types of exertions (isometric, dynamic, repetitive, etc.) and may affect the neuromuscular system differently. For example, muscle fatigue generated by static posture may produce results analogous to the current study. But sustained use of awkward non-neutral (flexed, rotated, laterally bent, etc.) head-neck postures may have a completely different response due to the passive tissues deformation.

Fatigue due to repetitive dynamic loading may affect response of muscles as well as passive tissues evoking different post-fatigue behavior. Future studies should look at the effect of fatigue due to different types of work exertions on the stability and recovery of the cervical spine.

Second, in the current study, a rating of 8 on Borg discomfort scale was used as an indicator of fatigue. Such high level of discomfort may be unlikely during work exertions, especially for the cervical spine. Future studies should investigate lower discomfort ratings (2, 4, 6, etc.) and their effect on the fatigue and recovery of cervical spine. This may aid in the development of a work-rest period matrix based on the subjective ratings of the discomfort.

Third, a constant load was used to induce fatigue during the Sorenson protocol. The magnitude of the weight was small and was independent of the participant's MVC strength. This is one of the reasons for the inter-participant variability in the endurance time. This is also a reason for the post-fatigue insignificant change in the median frequency. It is recommended for the future research to use a load as a percentage of the MVC. This will not only standardize the fatigue development process between the participants, but will also facilitate development of work-rest model for exertions with specific MVC demand.

Fourth, in this study the changes in the stability of cervical spine were tested by using FRP and SP procedures simultaneously. Although this experimental design allowed us to evaluate multiple parameters simultaneously, it is possible that one procedure may have affected the outcomes during other procedure. Furthermore, the preparation time (10 to 12 minutes) required to completing the FRP and SP procedures forced us to use a rest period of 15 minutes (minimum possible). A good amount of recovery was observed within this time window. Future studies should consider using different experimental designs, perhaps FRP and SP separately, to be able to monitor smaller rest periods. This will facilitate development of mathematical models for recovery process which can further aid in the quantification of precise work-rest protocols

Fifth, the participants in this research were chosen as a convenience sample of students at the West Virginia University. Accordingly, the mean age of the participants (26.6 ± 4.2) was lower than the mean age of the working population. Furthermore, various other characteristics such as force exertion strength, endurance time, discomfort-fatigue relationship for the workers who are routinely exposed to the work-related risk factors may be different than the participants

used in this study. Future research should test participants from the occupational groups with a high prevalence of neck MSD.

Sixth, in the SP study the same preload was used independent of the gender. This may produce difference in the gender response. Using pre-load as a certain percent of MVC may allow better control. However, very little is known about the relationship between the pre-load and muscle reflex response. Future study should evaluate this relationship to improve designs of SP protocols.

7.6 Practical Implication

A series of variables related to the load sharing and reflexive response of the active and passive structures of the cervical spine were investigated in this research. The recovery behavior of the variables that showed significant post-fatigue changes were quantified. Furthermore, the effect of gender in the behavior of these variables was also assessed. Altogether, the results of this study provide a comprehensive understanding of post-fatigue changes in the stability of the cervical spine. This understanding is necessary to improve workplace methods, especially the work-rest models to reduce the incidence of neck MSD.

Head-neck exertions are common among several occupational groups, such as modern offices, assembly lines, food processing, agriculture, wholesale and retail industry, fishing, healthcare, etc. (Dunning et al. 2010). These exertions lead to muscle fatigue, which is believed to be one of the precursor of the work-related MSDs. The findings of the current study are a step forward towards establishment of a viable fatigue related neck MSDs development pathway. The current study is expected to serve as the first step in a continuum of research to improve our understanding of the mechanism of pathogenesis of cervical spine disorders caused by neck muscle fatigue. This will further aid in the development of workplace intervention strategies to curtail the incidence of cervical spine MSDs.

7.7 Conclusions

The main conclusions of this study are as follows:

1. The findings of this research showed that the neck extensor fatigue modulates the FRP parameters by reducing the FRR, decreasing the onset and offset angles and consequently expanding the myoelectric silence period. These modulations in the FRP parameters

suggest that the stability of the cervical spine may be compromised due to the reduced force generation capacity of the fatigued neck muscles, resulting in an early engagement of the passive tissues.

2. The SP parameters provide additional insight into the post-fatigue changes in the neuromuscular responses critical to the spinal stability. Reduced stiffness and delayed temporal response (onset delay, time to peak and peak to peak) observed during the SP protocol further substantiate that the neck muscle fatigue compromises the stability of the cervical spine.
3. Majority of the parameters showed a complete recovery in the first 30 minutes. A recovery of about 79% to 95% was observed during the first 15 minutes and during the next 15 minutes a recovery of about 5% to 11% was observed. This suggests that the recovery process follows an exponential model.
4. Some differences were observed between females and males: Females showed higher endurance time, higher FRR, higher reflex gain and reflex amplitude, lower reflex latency, and lower stiffness. A different mechanism of fatigue related injuries among the females may be likely due to these differences between the females and males.
5. A new SP temporal parameter, peak to peak was established in this study. We believe that the peak to peak parameter can be a better option compared to time to peak parameter, because of its straightforward computation method.

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APPENDICES

Appendix A: IRB Approval

CONSENT AND INFORMATION FORM

FRP ICF

Principal Investigator: Nimbarte, Ashish
Department: ENGINEERING - Ind./Mgt. Sys. Engineering
Tracking Number: H-24575

Study Title:

Flexion-relaxation response induced by neck extensor muscle fatigue and postural changes

Co-Investigator(s):

Zreiqat, Majed

Sponsor

Contact Persons

In the event you experience any side effects or injury related to this research, you should contact Dr. Nimbarte at 304/293-9473. (After hours contact Dr. Nimbarte at 225/226-8813.) If you have any questions, concerns, or complaints about this research, you can contact Dr. Nimbarte at 304/293-9473 or Majed Zreiqat at 304/293-0486

For information regarding your rights as a research subject, you may contact the Office of Research Compliance at 304/293-7073.

Introduction

In addition if you would like to discuss problems, concerns, have suggestions related to research, or would like to offer input about the research, contact the Office of Research Integrity and Compliance at 304-293-7073.

Tracking #: H-24575
Approved On: 04/29/2013
Valid Through: 04/28/2014
Last Amended: N/A

Page 1 of 5

Initials

Date

You, _____, have been asked to participate in this research study, which has been explained to you by Dr. Ashish Nimbarte, Ph.D., and Majed Zreiqat, M.S. This study is being conducted by Dr. Ashish Nimbarte, Ph.D., and Majed Zreiqat, M.S in the Department of Industrial and Management Systems Engineering (IMSE) at West Virginia University. This research is being conducted to fulfill the requirements for a doctoral dissertation of Mr. Majed Zreiqat in the area of cervical spine Flexion-Relaxation Phenomenon in the Department of IMSE at West Virginia University, under the supervision of Dr. Nimbarte.

Purposes of the Study

The purpose of this study is to learn more about the effect of fatigue and shoulder shrug on Flexion-Relaxation Phenomenon parameters for cervical spine. WVU expects to enroll approximately 40 subjects; a total of approximately 40 subjects at all sites are expected to participate in this study.

Description of Procedures

The purpose of this study is to investigate the effect of fatigue and postural changes on the neck and head stability. In the study neck muscles activities and motion will be recorded. Subjects will perform the Flexion laxation procedure as follows: Subjects will stand still for 2 seconds, bend the neck to the maximum within 5 seconds, maintain this position for 5 second, and then return back to the starting position within 5 seconds. Subjects' movement will be controlled using a metronome with audible sound. This procedure will be repeated three times using normal and shrugged shoulder posture pre and post fatigue. Fatigue will be induced using the Sorensen procedure. In this procedure subjects will lay on a table facing down with shoulders being leveled with the edge of the table and arms maintained on the sides. During this procedure, subjects will be asked to rate the level of discomfort in the neck muscles every minute using 10 point Borg scale (1 = Nothing at all and 10 = Very severe pain or discomfort). This position is maintained until it can't be held anymore or when a rating of level 8 in Borg scale is reached, whichever comes first. The duration of this experiment is about one hour. The data collected will be used to investigate the effect of fatigue and shoulder shrug on the neck—head stability.

Risks and Discomforts

There are no known or expected risks from participating in this study except a mild discomfort in the neck area associated with the fatigue protocol which is expected to disappear soon after the experiment is completed.

Alternatives

You do not have to participate in this study.

Alternatives that could be considered in your case include _____.

Benefits

You may not receive any direct benefit from this study. The knowledge gained from this study may eventually benefit others.

Financial Considerations

No monetary compensation will be given for participating in this study and participants do not incur any costs as a result of participation in the study. Voluntary Compensation It is very important for you to understand that neither the investigator nor WVU or its associated affiliates has the funds set aside to pay for the cost of lost work wages or any care or treatment that might be necessary because you get hurt or sick taking part in this study. Any injuries that may result from this study would not be eligible for Workers' Compensation as this is not job related injury. Understand that any treatments necessary will be billed to the participant or to your personal health insurance, and you may wish to consult your insurance provider before participating in this study.

Confidentiality

Any information about you that is obtained as a result of your participation in this research will be kept as confidential as legally possible. Your research records and test results, just like hospital records, may be subpoenaed by court order or may be inspected by federal regulatory authorities without your additional consent.

Audiotapes or videotapes will be kept locked up and will be destroyed as

Tracking #: H-24575
Approved On: 04/29/2013
Valid Through: 04/28/2014
Last Amended: N/A

Page 3 of 5

Initials Date

Tracking #: H-24575

soon as possible after the research is finished.

In any publications that result from this research, neither your name nor any information from which you might be identified will be published without your consent.

Voluntary Participation

Participation in this study is voluntary. You are free to withdraw your consent to participate in this study at any time. Refusal to participate or withdrawal will not affect your future care, [or your employee status at West Virginia University or your class standing or grades, as appropriate] and will involve no penalty to you. In the event new information becomes available that may affect your willingness to participate in this study, this information will be given to you so that you can make an informed decision about whether or not to continue your participation. You have been given the opportunity to ask questions about the research, and you have received answers concerning areas you did not understand.

Tracking #: H-24575
Approved On: 04/29/2013
Valid Through: 04/28/2014
Last Amended: N/A

Page 4 of 5

Initials _____ Date _____

Tracking #: H-24575

Upon signing this form, you will receive a copy.

I willingly consent to participate in this research.

Signature of Subject or
Subjects Legal Representative

Printed Name

Date

Time

The participant has had the opportunity to have questions addressed. The participant willingly agrees to be in the study.

Signature of Investigator or
Co-Investigator

Printed Name

Date

Time

Tracking #: H-24575
Approved On: 04/29/2013
Valid Through: 04/28/2014
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Page 5 of 5

Initials

Date

Appendix B: Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire (PAR-Q)

For most people physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

YES NO

☐	☐	1. Has your doctor ever said you have a heart trouble and should only do physical activity recommended by a doctor?
☐	☐	2. Do you frequently suffer from chest pain?
☐	☐	3. Do you often faint or have spells of severe dizziness?
☐	☐	4. Has your doctor ever said your blood pressure was too high?
☐	☐	5. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by, or might be made worse with exercise.
☐	☐	6. Is there any good physical reason why you should not follow an activity program even if you want to?
☐	☐	7. Are you 65 and not accustomed to vigorous exercise?

If you answer "yes" to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary.

I have read this questionnaire, I understand it does not provide medical assessment in lieu of a physical examination by a physician.

Participant's signature: _____

Date: _____

Investigator's signature: _____

Date: _____

Adapted from PAR-Q validation report, British Columbia department of Health, June 1975.

Reference: BQ Hafen, WWK Hoeger (1994), Wellness: Guidelines for a healthy lifestyle. Englewood, CO: Morton Pub. Co.

Appendix C: Participants data

Subject	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Pulley Ht*	51	50	51	51	50	51	53	52	51	51	49	47	51	47	48	48	52	48	48	49
Age	24	26	25	28	22	23	26	26	20	21	30	36	33	23	25	25	31	29	28	22
Gender	M	M	M	M	M	M	M	M	M	M	F	F	F	F	F	F	F	F	F	F
Ht (cm)	170	169	172	170	167	183	179	+181	180	185	163	151	169	160	160	154	168	170	164	170
Wt (Kg)	68	57	77	62	65	82	78.5	71	76	68	52	48.5	72	59	61	46.5	63	55	47	56.7
C7-C6 Dist*	2.5	2.0	2.0	1.85	2.1	2.1	2.25	2.0	2.5	2.5	2.0	2.0	2.0	2.3	2.0	2.3	1.8	2.0	1.8	2.0
Rating discomfort level from 1-10																				
1 min	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2 min	3	3	3	1	2	2	1	2	2	2	2	2	3	2	2	1	1	1	2	1
3 min	4	4	5	2	3	3	2	2	2	3	2	3	4	2	3	1	2	2	3	1
4 min	5	5	6	3	4	4	3	3	3	3	3	4	5	3	3	1	3	3	4	2
5 min	6	6	7	4	5	5	3	3	3	4	5	6	6	4	4	2	4	4	5	2
6 min	7	7	7	4	6	6	4	4	4	4	7	7	7	5	4	2	5	5	6	2
7 min	8	8	8	5	7	7	4	4	5	5	8	7	8	6	5	3	6	6	7	2
8 min				5	8	8	4	5	6	5		8		7	5	3	6	7	8	3
9 min				6		8	5	5	6	6				8	5	4	7	7	8	3
10 min				6			6	6	7	6					5	4	8	8		3
11 min				7			7	6	7	7					6	5	8	8		3

Subject Time	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
12 min				7			8	7	7	7					6	5				4
13 min				7			8	7	8	7					6	6				4
14 min				7			8	8	8	8					6	6				4
15 min				8				8	8	8					7	7				4
16 min										8					7	7				5
17 min															7	8				5
18 min															7	8				5
19 min															7	8				5
20 min															8					6
21 min															8					6
22 min																				7
23 min																				7
24 min																				7
25 min																				7
26 min																				8
27 min																				8

* In inches

Appendix D: Normality test for FRP parameters

Table 25: Normality test for FRP parameters - fatigue

FATIGUE		Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Residual for FRR_R	PRE	.098	20	.200 [*]	.976	20	.868
	POST	.106	20	.200 [*]	.965	20	.648
Residual for FRR_L	PRE	.111	20	.200 [*]	.974	20	.827
	POST	.131	20	.200 [*]	.960	20	.544
Residual for ONSET_R	PRE	.155	20	.200 [*]	.912	20	.068
	POST	.115	20	.200 [*]	.942	20	.266
Residual for ONSET_L	PRE	.161	20	.184	.940	20	.235
	POST	.169	20	.138	.923	20	.113
Residual for OFFSET_R	PRE	.107	20	.200 [*]	.979	20	.921
	POST	.117	20	.200 [*]	.964	20	.626
Residual for OFFSET_L	PRE	.127	20	.200 [*]	.976	20	.881
	POST	.160	20	.192	.955	20	.444
Residual for T1_R	PRE	.171	20	.128	.850	20	.005
	POST	.126	20	.200 [*]	.964	20	.620
Residual for T1_L	PRE	.201	20	.034	.800	20	.001
	POST	.101	20	.200 [*]	.969	20	.740
Residual for T2_R	PRE	.131	20	.200 [*]	.955	20	.453
	POST	.071	20	.200 [*]	.979	20	.927
Residual for T2_L	PRE	.160	20	.194	.948	20	.334
	POST	.149	20	.200 [*]	.956	20	.471
Residual for EXPANSION_R	PRE	.136	20	.200 [*]	.863	20	.009
	POST	.080	20	.200 [*]	.976	20	.875
Residual for EXPANSION_L	PRE	.141	20	.200 [*]	.842	20	.004
	POST	.109	20	.200 [*]	.970	20	.748

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 26: Normality test for FRP parameters - gender

	GENDER	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Residual for FRR_R	MALE	.125	20	.200 [*]	.966	20	.676
	FEMALE	.131	20	.200 [*]	.964	20	.618
Residual for FRR_L	MALE	.127	20	.200 [*]	.964	20	.628
	FEMALE	.162	20	.177	.971	20	.779
Residual for ONSET_R	MALE	.124	20	.200 [*]	.944	20	.286
	FEMALE	.124	20	.200 [*]	.931	20	.163
Residual for ONSET_L	MALE	.172	20	.121	.941	20	.248
	FEMALE	.186	20	.069	.890	20	.027
Residual for OFFSET_R	MALE	.157	20	.200 [*]	.917	20	.088
	FEMALE	.111	20	.200 [*]	.967	20	.692
Residual for OFFSET_L	MALE	.180	20	.090	.919	20	.096
	FEMALE	.127	20	.200 [*]	.962	20	.590
Residual for T1_R	MALE	.136	20	.200 [*]	.938	20	.221
	FEMALE	.151	20	.200 [*]	.956	20	.464
Residual for T1_L	MALE	.160	20	.191	.931	20	.161
	FEMALE	.158	20	.200 [*]	.959	20	.533
Residual for T2_R	MALE	.135	20	.200 [*]	.952	20	.398
	FEMALE	.133	20	.200 [*]	.962	20	.582
Residual for T2_L	MALE	.143	20	.200 [*]	.956	20	.473
	FEMALE	.163	20	.169	.938	20	.221
Residual for EXPANSION_R	MALE	.101	20	.200 [*]	.987	20	.993
	FEMALE	.143	20	.200 [*]	.963	20	.599
Residual for EXPANSION_L	MALE	.105	20	.200 [*]	.980	20	.938
	FEMALE	.124	20	.200 [*]	.968	20	.723

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Appendix E: Normality test for SP parameters

Table 27: Normality test for SP temporal and magnitude parameters residuals - fatigue

FATIGUE		Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Residual for OD_R	PRE	.163	20	.174	.932	20	.168
	POST	.138	20	.200 [*]	.939	20	.234
Residual for OD_L	PRE	.170	20	.134	.908	20	.058
	POST	.145	20	.200 [*]	.959	20	.521
Residual for TTP_R	PRE	.150	20	.200 [*]	.924	20	.118
	POST	.125	20	.200 [*]	.965	20	.657
Residual for TTP_L	PRE	.149	20	.200 [*]	.930	20	.153
	POST	.098	20	.200 [*]	.972	20	.788
Residual for PTP_R	PRE	.170	20	.131	.950	20	.367
	POST	.116	20	.200 [*]	.959	20	.517
Residual for PTP_L	PRE	.158	20	.200 [*]	.960	20	.537
	POST	.152	20	.200 [*]	.949	20	.352
Residual for RefAmp_R	PRE	.141	20	.200 [*]	.981	20	.941
	POST	.122	20	.200 [*]	.960	20	.550
Residual for RefAmp_L	PRE	.110	20	.200 [*]	.967	20	.695
	POST	.080	20	.200 [*]	.979	20	.917
Residual for RefGain_R	PRE	.092	20	.200 [*]	.986	20	.988
	POST	.134	20	.200 [*]	.959	20	.519
Residual for RefGain_L	PRE	.154	20	.200 [*]	.963	20	.596
	POST	.100	20	.200 [*]	.976	20	.872

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 28: Normality test for stiffness residual - fatigue

Fatigue		Kolmogorov-Smirnov ^b			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Residual for Intrinsic_stiffness	PRE	.111	20	.200 [*]	.958	20	.506
	POST	.104	20	.200 [*]	.975	20	.849
Residual for Effective_stiffness	PRE	.118	20	.200 [*]	.952	20	.405
	POST	.114	20	.200 [*]	.956	20	.463

*. This is a lower bound of the true significance.

a. There are no valid cases for Residual for Intrinsic_stiffness when Fatigue = .000. Statistics cannot be computed for this level.

b. Lilliefors Significance Correction

d. There are no valid cases for Residual for Effective_stiffness when Fatigue = .000. Statistics cannot be computed for this level.

Table 29: Normality test for SP temporal and magnitude parameters residuals - gender

	GENDER	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Residual for OD_R	MALE	.116	20	.200 [*]	.952	20	.404
	FEMALE	.162	20	.180	.934	20	.181
Residual for OD_L	MALE	.138	20	.200 [*]	.958	20	.510
	FEMALE	.154	20	.200 [*]	.955	20	.449
Residual for TTP_R	MALE	.113	20	.200 [*]	.944	20	.286
	FEMALE	.115	20	.200 [*]	.935	20	.194
Residual for TTP_L	MALE	.135	20	.200 [*]	.947	20	.327
	FEMALE	.178	20	.097	.919	20	.097
Residual for PTP_R	MALE	.177	20	.099	.950	20	.374
	FEMALE	.091	20	.200 [*]	.965	20	.642
Residual for PTP_L	MALE	.141	20	.200 [*]	.945	20	.304
	FEMALE	.126	20	.200 [*]	.948	20	.334
Residual for RefAmp_R	MALE	.073	20	.200 [*]	.991	20	.999
	FEMALE	.178	20	.095	.947	20	.329
Residual for RefAmp_L	MALE	.134	20	.200 [*]	.963	20	.611
	FEMALE	.130	20	.200 [*]	.965	20	.644
Residual for RefGain_R	MALE	.103	20	.200 [*]	.984	20	.972
	FEMALE	.104	20	.200 [*]	.982	20	.961
Residual for RefGain_L	MALE	.132	20	.200 [*]	.971	20	.773
	FEMALE	.117	20	.200 [*]	.968	20	.703

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 30: Normality test for stiffness residuals - gender

	Gender	Kolmogorov-Smirnov ^b			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Residual for Intrinsic_stiffness	MALE	.128	20	.200 [*]	.955	20	.450
	FEMALE	.088	20	.200 [*]	.976	20	.879
Residual for Effective_stiffness	MALE	.089	20	.200 [*]	.971	20	.777
	FEMALE	.106	20	.200 [*]	.965	20	.650

*. This is a lower bound of the true significance.

a. There are no valid cases for Residual for Intrinsic_stiffness when Gender = .000. Statistics cannot be computed for this level.

b. Lilliefors Significance Correction

d. There are no valid cases for Residual for Effective_stiffness when Gender = .000. Statistics cannot be computed for this level.

Appendix F: Levene's test of equality of error variances for FRP parameters

Table 31: Levene's test for FRP parameters

	F	df1	df2	Sig.
FRR_R	1.297	3	36	.290
ONSET_R	1.126	3	36	.352
OFFSET_R	3.694	3	36	.020
T1_R	9.209	3	36	.000
T2_R	4.239	3	36	.012
EXPANSION_R	6.117	3	36	.002
FRR_L	.556	3	36	.648
ONSET_L	1.036	3	36	.388
OFFSET_L	4.437	3	36	.009
T1_L	9.416	3	36	.000
T2_L	6.184	3	36	.002
EXPANSION_L	8.100	3	36	.000

Table 32: Levene's test - Pooled side

		Levene Statistic	df1	df2	Sig.
FRR	Based on Mean	2.316	1	38	.136
	Based on Median	2.304	1	38	.137
	Based on Median and with adjusted df	2.304	1	37.999	.137
	Based on trimmed mean	2.265	1	38	.141
ONSET	Based on Mean	.215	1	38	.645
	Based on Median	.175	1	38	.678
	Based on Median and with adjusted df	.175	1	36.187	.678
	Based on trimmed mean	.214	1	38	.646
OFFSETL	Based on Mean	.285	1	38	.597
	Based on Median	.170	1	38	.683
	Based on Median and with adjusted df	.170	1	34.436	.683
	Based on trimmed mean	.237	1	38	.629
T1	Based on Mean	1.181	1	38	.284
	Based on Median	.944	1	38	.337
	Based on Median and with adjusted df	.944	1	26.632	.340
	Based on trimmed mean	1.045	1	38	.313
T2	Based on Mean	.771	1	38	.385
	Based on Median	.276	1	38	.602
	Based on Median and with adjusted df	.276	1	37.108	.602
	Based on trimmed mean	.774	1	38	.385
EXPANSION	Based on Mean	.408	1	38	.527
	Based on Median	.390	1	38	.536
	Based on Median and with adjusted df	.390	1	27.727	.537
	Based on trimmed mean	.403	1	38	.529

Appendix G: Levene's Test of Equality of Error Variances for SP parameters

Table 33: Levene's test for SP parameters

	F	df1	df2	Sig.
OD_R	1.513	3	36	.228
TTP_R	.979	3	36	.413
PTP_R	1.821	3	36	.161
RA_R	1.816	3	36	.162
RG_R	2.850	3	36	.051
OD_L	1.941	3	36	.140
TTP_L	.131	3	36	.941
PTP_L	1.246	3	36	.307
RA_L	1.363	3	36	.270
RG_L	5.075	3	36	.005

Table 34: Levene's test for SP parameters – pooled side

	F	df1	df2	Sig.
OD	1.728	3	36	.179
TTP	.440	3	36	.725
PTP	1.426	3	36	.251
RA	1.667	3	36	.191
RG	4.252	3	36	.011

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE

Table 35: Levene's test for stiffness

	F	df1	df2	Sig.
Intrinsic_stiffness	.065	3	36	.978
Effective_stiffness	.318	3	36	.812

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Gender + Fatigue + Gender * Fatigue

Appendix H: Median frequency and power spectrum statistical analysis

General Linear Model: Median_frequency versus Muscle, Sub No, ...

Factor	Type	Levels	Values
Muscle	fixed	2	1, 2
Sub No	random	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Gender (male, female)	fixed	2	1, 2
Time (start, end)	fixed	2	1, 2

Analysis of Variance for Median_frequency, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muscle	1	22.8	22.8	22.8	0.10	0.752
Sub No	9	24672.1	24672.1	2741.3	12.05	0.000
Gender (male, female)	1	2692.9	2692.9	2692.9	11.83	0.001
Time (start, end)	1	8.1	8.1	8.1	0.04	0.851
Gender (male, female)* Time (start, end)	1	178.1	178.1	178.1	0.78	0.378
Error	146	33226.7	33226.7	227.6		
Total	159	60800.7				

S = 15.0858 R-Sq = 45.35% R-Sq(adj) = 40.49%

General Linear Model: 8-16 Hz versus Muscle, Sub No, ...

Factor	Type	Levels	Values
Muscle	fixed	2	1, 2
Sub No	random	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Gender (male, female)	fixed	2	1, 2
Time (start, end)	fixed	2	1, 2

Analysis of Variance for 8-16 Hz, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muscle	1	0.0343	0.0343	0.0343	0.04	0.851
Sub No	9	92.4886	92.4886	10.2765	10.57	0.000
Gender (male, female)	1	15.9167	15.9167	15.9167	16.38	0.000
Time (start, end)	1	9.6379	9.6379	9.6379	9.92	0.002
Gender (male, female)* Time (start, end)	1	3.7204	3.7204	3.7204	3.83	0.052
Error	146	141.9118	141.9118	0.9720		
Total	159	263.7098				

S = 0.985900 R-Sq = 46.19% R-Sq(adj) = 41.39%

General Linear Model: 16-32 Hz versus Muscle, Sub No, ...

Factor	Type	Levels	Values
Muscle	fixed	2	1, 2
Sub No	random	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Gender (male, female)	fixed	2	1, 2
Time (start, end)	fixed	2	1, 2

Analysis of Variance for 16-32 Hz, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muscle	1	2005	2005	2005	0.33	0.568
Sub No	9	607259	607259	67473	11.03	0.000
Gender (male, female)	1	115090	115090	115090	18.81	0.000
Time (start, end)	1	49600	49600	49600	8.11	0.005
Gender (male, female)* Time (start, end)	1	20933	20933	20933	3.42	0.066
Error	146	893327	893327	6119		
Total	159	1688214				

S = 78.2220 R-Sq = 47.08% R-Sq(adj) = 42.37%

General Linear Model: 32-63 Hz versus Muscle, Sub No, ...

Factor	Type	Levels	Values
Muscle	fixed	2	1, 2
Sub No	random	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Gender (male, female)	fixed	2	1, 2
Time (start, end)	fixed	2	1, 2

Analysis of Variance for 32-63 Hz, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muscle	1	65049	65049	65049	0.67	0.416
Sub No	9	10066146	10066146	1118461	11.43	0.000
Gender (male, female)	1	1593957	1593957	1593957	16.30	0.000
Time (start, end)	1	616922	616922	616922	6.31	0.013
Gender (male, female)* Time (start, end)	1	331009	331009	331009	3.38	0.068
Error	146	14280730	14280730	97813		
Total	159	26953812				

S = 312.751 R-Sq = 47.02% R-Sq(adj) = 42.30%

General Linear Model: 63-125 Hz versus Muscle, Sub No, ...

Factor	Type	Levels	Values
Muscle	fixed	2	1, 2
Sub No	random	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Gender (male, female)	fixed	2	1, 2
Time (start, end)	fixed	2	1, 2

Analysis of Variance for 63-125 Hz, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muscle	1	17502	17502	17502	0.20	0.654
Sub No	9	10719604	10719604	1191067	13.71	0.000
Gender (male, female)	1	403079	403079	403079	4.64	0.033
Time (start, end)	1	402160	402160	402160	4.63	0.033
Gender (male, female)* Time (start, end)	1	62472	62472	62472	0.72	0.398
Error	146	12682018	12682018	86863		
Total	159	24286835				

S = 294.726 R-Sq = 47.78% R-Sq(adj) = 43.13%

General Linear Model: 125-250 Hz versus Muscle, Sub No, ...

Factor	Type	Levels	Values
Muscle	fixed	2	1, 2
Sub No	random	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Gender (male, female)	fixed	2	1, 2
Time (start, end)	fixed	2	1, 2

Analysis of Variance for 125-250 Hz, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muscle	1	6931	6931	6931	0.24	0.622
Sub No	9	2122052	2122052	235784	8.32	0.000
Gender (male, female)	1	54543	54543	54543	1.92	0.168
Time (start, end)	1	66069	66069	66069	2.33	0.129
Gender (male, female)* Time (start, end)	1	7198	7198	7198	0.25	0.615
Error	146	4138430	4138430	28345		
Total	159	6395223				

S = 168.361 R-Sq = 35.29% R-Sq(adj) = 29.53%

General Linear Model: 250-500 Hz versus Muscle, Sub No, ...

Factor	Type	Levels	Values
Muscle	fixed	2	1, 2
Sub No	random	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Gender (male, female)	fixed	2	1, 2
Time (start, end)	fixed	2	1, 2

Analysis of Variance for 250-500 Hz, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muscle	1	289.9	289.9	289.9	0.30	0.586
Sub No	9	80031.4	80031.4	8892.4	9.15	0.000
Gender (male, female)	1	640.4	640.4	640.4	0.66	0.418
Time (start, end)	1	3737.0	3737.0	3737.0	3.85	0.052
Gender (male, female)* Time (start, end)	1	185.0	185.0	185.0	0.19	0.663
Error	146	141886.5	141886.5	971.8		
Total	159	226770.2				

S = 31.1741 R-Sq = 37.43% R-Sq(adj) = 31.86%

Appendix I: Multivariate analysis for FRP parameters

Table 36: Univariate analysis for FRR – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
FRR_SIDE	Pillai's Trace	.009	.339 ^b	1.000	36.000	.564
	Wilks' Lambda	.991	.339 ^b	1.000	36.000	.564
	Hotelling's Trace	.009	.339 ^b	1.000	36.000	.564
	Roy's Largest Root	.009	.339 ^b	1.000	36.000	.564
FRR_SIDE * GENDER	Pillai's Trace	.053	2.004 ^b	1.000	36.000	.166
	Wilks' Lambda	.947	2.004 ^b	1.000	36.000	.166
	Hotelling's Trace	.056	2.004 ^b	1.000	36.000	.166
	Roy's Largest Root	.056	2.004 ^b	1.000	36.000	.166
FRR_SIDE * FATIGUE	Pillai's Trace	.002	.073 ^b	1.000	36.000	.789
	Wilks' Lambda	.998	.073 ^b	1.000	36.000	.789
	Hotelling's Trace	.002	.073 ^b	1.000	36.000	.789
	Roy's Largest Root	.002	.073 ^b	1.000	36.000	.789
FRR_SIDE * GENDER * FATIGUE	Pillai's Trace	.000	.017 ^b	1.000	36.000	.898
	Wilks' Lambda	1.000	.017 ^b	1.000	36.000	.898
	Hotelling's Trace	.000	.017 ^b	1.000	36.000	.898
	Roy's Largest Root	.000	.017 ^b	1.000	36.000	.898

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: FRR_SIDE

b. Exact statistic

Table 37: Univariate analysis for onset angle – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
ONSET_SIDE	Pillai's Trace	.005	.187 ^b	1.000	36.000	.668
	Wilks' Lambda	.995	.187 ^b	1.000	36.000	.668
	Hotelling's Trace	.005	.187 ^b	1.000	36.000	.668
	Roy's Largest Root	.005	.187 ^b	1.000	36.000	.668
ONSET_SIDE * GENDER	Pillai's Trace	.065	2.507 ^b	1.000	36.000	.122
	Wilks' Lambda	.935	2.507 ^b	1.000	36.000	.122
	Hotelling's Trace	.070	2.507 ^b	1.000	36.000	.122
	Roy's Largest Root	.070	2.507 ^b	1.000	36.000	.122
ONSET_SIDE * FATIGUE	Pillai's Trace	.072	2.803 ^b	1.000	36.000	.103
	Wilks' Lambda	.928	2.803 ^b	1.000	36.000	.103
	Hotelling's Trace	.078	2.803 ^b	1.000	36.000	.103
	Roy's Largest Root	.078	2.803 ^b	1.000	36.000	.103
ONSET_SIDE * GENDER * FATIGUE	Pillai's Trace	.039	1.450 ^b	1.000	36.000	.236
	Wilks' Lambda	.961	1.450 ^b	1.000	36.000	.236
	Hotelling's Trace	.040	1.450 ^b	1.000	36.000	.236
	Roy's Largest Root	.040	1.450 ^b	1.000	36.000	.236

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: ONSET_SIDE

b. Exact statistic

Table 38: Univariate analysis for offset angle – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
OFFSET_SIDE	Pillai's Trace	.055	2.086 ^b	1.000	36.000	.157
	Wilks' Lambda	.945	2.086 ^b	1.000	36.000	.157
	Hotelling's Trace	.058	2.086 ^b	1.000	36.000	.157
	Roy's Largest Root	.058	2.086 ^b	1.000	36.000	.157
OFFSET_SIDE * GENDER	Pillai's Trace	.055	2.079 ^b	1.000	36.000	.158
	Wilks' Lambda	.945	2.079 ^b	1.000	36.000	.158
	Hotelling's Trace	.058	2.079 ^b	1.000	36.000	.158
	Roy's Largest Root	.058	2.079 ^b	1.000	36.000	.158
OFFSET_SIDE * FATIGUE	Pillai's Trace	.063	2.404 ^b	1.000	36.000	.130
	Wilks' Lambda	.937	2.404 ^b	1.000	36.000	.130
	Hotelling's Trace	.067	2.404 ^b	1.000	36.000	.130
	Roy's Largest Root	.067	2.404 ^b	1.000	36.000	.130
OFFSET_SIDE * GENDER * FATIGUE	Pillai's Trace	.041	1.527 ^b	1.000	36.000	.225
	Wilks' Lambda	.959	1.527 ^b	1.000	36.000	.225
	Hotelling's Trace	.042	1.527 ^b	1.000	36.000	.225
	Roy's Largest Root	.042	1.527 ^b	1.000	36.000	.225

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: OFFSET_SIDE

b. Exact statistic

Table 39: Univariate analysis for T1 – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
T1_SIDE	Pillai's Trace	.021	.786 ^b	1.000	36.000	.381
	Wilks' Lambda	.979	.786 ^b	1.000	36.000	.381
	Hotelling's Trace	.022	.786 ^b	1.000	36.000	.381
	Roy's Largest Root	.022	.786 ^b	1.000	36.000	.381
T1_SIDE * GENDER	Pillai's Trace	.063	2.430 ^b	1.000	36.000	.128
	Wilks' Lambda	.937	2.430 ^b	1.000	36.000	.128
	Hotelling's Trace	.067	2.430 ^b	1.000	36.000	.128
	Roy's Largest Root	.067	2.430 ^b	1.000	36.000	.128
T1_SIDE * FATIGUE	Pillai's Trace	.020	.750 ^b	1.000	36.000	.392
	Wilks' Lambda	.980	.750 ^b	1.000	36.000	.392
	Hotelling's Trace	.021	.750 ^b	1.000	36.000	.392
	Roy's Largest Root	.021	.750 ^b	1.000	36.000	.392
T1_SIDE * GENDER * FATIGUE	Pillai's Trace	.002	.087 ^b	1.000	36.000	.769
	Wilks' Lambda	.998	.087 ^b	1.000	36.000	.769
	Hotelling's Trace	.002	.087 ^b	1.000	36.000	.769
	Roy's Largest Root	.002	.087 ^b	1.000	36.000	.769

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: T1_SIDE

b. Exact statistic

Table 40: Univariate analysis for T2 – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
T2_SIDE	Pillai's Trace	.008	.283 ^b	1.000	36.000	.598
	Wilks' Lambda	.992	.283 ^b	1.000	36.000	.598
	Hotelling's Trace	.008	.283 ^b	1.000	36.000	.598
	Roy's Largest Root	.008	.283 ^b	1.000	36.000	.598
T2_SIDE * GENDER	Pillai's Trace	.029	1.060 ^b	1.000	36.000	.310
	Wilks' Lambda	.971	1.060 ^b	1.000	36.000	.310
	Hotelling's Trace	.029	1.060 ^b	1.000	36.000	.310
	Roy's Largest Root	.029	1.060 ^b	1.000	36.000	.310
T2_SIDE * FATIGUE	Pillai's Trace	.035	1.290 ^b	1.000	36.000	.264
	Wilks' Lambda	.965	1.290 ^b	1.000	36.000	.264
	Hotelling's Trace	.036	1.290 ^b	1.000	36.000	.264
	Roy's Largest Root	.036	1.290 ^b	1.000	36.000	.264
T2_SIDE * GENDER * FATIGUE	Pillai's Trace	.043	1.633 ^b	1.000	36.000	.209
	Wilks' Lambda	.957	1.633 ^b	1.000	36.000	.209
	Hotelling's Trace	.045	1.633 ^b	1.000	36.000	.209
	Roy's Largest Root	.045	1.633 ^b	1.000	36.000	.209

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: T2_SIDE

b. Exact statistic

Table 41: Univariate analysis for Expansion – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
EXP_SIDE	Pillai's Trace	.008	.297 ^b	1.000	36.000	.589
	Wilks' Lambda	.992	.297 ^b	1.000	36.000	.589
	Hotelling's Trace	.008	.297 ^b	1.000	36.000	.589
	Roy's Largest Root	.008	.297 ^b	1.000	36.000	.589
EXP_SIDE * GENDER	Pillai's Trace	.022	.824 ^b	1.000	36.000	.370
	Wilks' Lambda	.978	.824 ^b	1.000	36.000	.370
	Hotelling's Trace	.023	.824 ^b	1.000	36.000	.370
	Roy's Largest Root	.023	.824 ^b	1.000	36.000	.370
EXP_SIDE * FATIGUE	Pillai's Trace	.001	.040 ^b	1.000	36.000	.842
	Wilks' Lambda	.999	.040 ^b	1.000	36.000	.842
	Hotelling's Trace	.001	.040 ^b	1.000	36.000	.842
	Roy's Largest Root	.001	.040 ^b	1.000	36.000	.842
EXP_SIDE * GENDER * FATIGUE	Pillai's Trace	.005	.169 ^b	1.000	36.000	.684
	Wilks' Lambda	.995	.169 ^b	1.000	36.000	.684
	Hotelling's Trace	.005	.169 ^b	1.000	36.000	.684
	Roy's Largest Root	.005	.169 ^b	1.000	36.000	.684

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: EXP_SIDE

b. Exact statistic

Appendix J: Multivariate analysis for SP parameters– side effect

Table 42: Univariate analysis for OD – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
OD_SIDE	Pillai's Trace	.001	.044 ^b	1.000	36.000	.835
	Wilks' Lambda	.999	.044 ^b	1.000	36.000	.835
	Hotelling's Trace	.001	.044 ^b	1.000	36.000	.835
	Roy's Largest Root	.001	.044 ^b	1.000	36.000	.835
OD_SIDE * GENDER	Pillai's Trace	.003	.090 ^b	1.000	36.000	.766
	Wilks' Lambda	.997	.090 ^b	1.000	36.000	.766
	Hotelling's Trace	.003	.090 ^b	1.000	36.000	.766
	Roy's Largest Root	.003	.090 ^b	1.000	36.000	.766
OD_SIDE * FATIGUE	Pillai's Trace	.001	.052 ^b	1.000	36.000	.820
	Wilks' Lambda	.999	.052 ^b	1.000	36.000	.820
	Hotelling's Trace	.001	.052 ^b	1.000	36.000	.820
	Roy's Largest Root	.001	.052 ^b	1.000	36.000	.820
OD_SIDE * GENDER * FATIGUE	Pillai's Trace	.055	2.087 ^b	1.000	36.000	.157
	Wilks' Lambda	.945	2.087 ^b	1.000	36.000	.157
	Hotelling's Trace	.058	2.087 ^b	1.000	36.000	.157
	Roy's Largest Root	.058	2.087 ^b	1.000	36.000	.157

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: OD_SIDE

b. Exact statistic

Table 43: Univariate analysis for TTP– side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
TTP_SIDE	Pillai's Trace	.010	.363 ^b	1.000	36.000	.551
	Wilks' Lambda	.990	.363 ^b	1.000	36.000	.551
	Hotelling's Trace	.010	.363 ^b	1.000	36.000	.551
	Roy's Largest Root	.010	.363 ^b	1.000	36.000	.551
TTP_SIDE * GENDER	Pillai's Trace	.080	3.135 ^b	1.000	36.000	.085
	Wilks' Lambda	.920	3.135 ^b	1.000	36.000	.085
	Hotelling's Trace	.087	3.135 ^b	1.000	36.000	.085
	Roy's Largest Root	.087	3.135 ^b	1.000	36.000	.085
TTP_SIDE * FATIGUE	Pillai's Trace	.075	2.931 ^b	1.000	36.000	.096
	Wilks' Lambda	.925	2.931 ^b	1.000	36.000	.096
	Hotelling's Trace	.081	2.931 ^b	1.000	36.000	.096
	Roy's Largest Root	.081	2.931 ^b	1.000	36.000	.096
TTP_SIDE * GENDER * FATIGUE	Pillai's Trace	.055	2.105 ^b	1.000	36.000	.155
	Wilks' Lambda	.945	2.105 ^b	1.000	36.000	.155
	Hotelling's Trace	.058	2.105 ^b	1.000	36.000	.155
	Roy's Largest Root	.058	2.105 ^b	1.000	36.000	.155

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: TTP_SIDE

b. Exact statistic

Table 44: Univariate analysis for PTP – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
PTP_SIDE	Pillai's Trace	.032	1.183 ^b	1.000	36.000	.284
	Wilks' Lambda	.968	1.183 ^b	1.000	36.000	.284
	Hotelling's Trace	.033	1.183 ^b	1.000	36.000	.284
	Roy's Largest Root	.033	1.183 ^b	1.000	36.000	.284
PTP_SIDE * GENDER	Pillai's Trace	.074	2.890 ^b	1.000	36.000	.098
	Wilks' Lambda	.926	2.890 ^b	1.000	36.000	.098
	Hotelling's Trace	.080	2.890 ^b	1.000	36.000	.098
	Roy's Largest Root	.080	2.890 ^b	1.000	36.000	.098
PTP_SIDE * FATIGUE	Pillai's Trace	.029	1.062 ^b	1.000	36.000	.310
	Wilks' Lambda	.971	1.062 ^b	1.000	36.000	.310
	Hotelling's Trace	.029	1.062 ^b	1.000	36.000	.310
	Roy's Largest Root	.029	1.062 ^b	1.000	36.000	.310
PTP_SIDE * GENDER * FATIGUE	Pillai's Trace	.012	.445 ^b	1.000	36.000	.509
	Wilks' Lambda	.988	.445 ^b	1.000	36.000	.509
	Hotelling's Trace	.012	.445 ^b	1.000	36.000	.509
	Roy's Largest Root	.012	.445 ^b	1.000	36.000	.509

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: PTP_SIDE

b. Exact statistic

Table 45: Univariate analysis for RG – side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
RG_SIDE	Pillai's Trace	.080	3.133 ^b	1.000	36.000	.085
	Wilks' Lambda	.920	3.133 ^b	1.000	36.000	.085
	Hotelling's Trace	.087	3.133 ^b	1.000	36.000	.085
	Roy's Largest Root	.087	3.133 ^b	1.000	36.000	.085
RG_SIDE * GENDER	Pillai's Trace	.013	.463 ^b	1.000	36.000	.500
	Wilks' Lambda	.987	.463 ^b	1.000	36.000	.500
	Hotelling's Trace	.013	.463 ^b	1.000	36.000	.500
	Roy's Largest Root	.013	.463 ^b	1.000	36.000	.500
RG_SIDE * FATIGUE	Pillai's Trace	.010	.348 ^b	1.000	36.000	.559
	Wilks' Lambda	.990	.348 ^b	1.000	36.000	.559
	Hotelling's Trace	.010	.348 ^b	1.000	36.000	.559
	Roy's Largest Root	.010	.348 ^b	1.000	36.000	.559
RG_SIDE * GENDER * FATIGUE	Pillai's Trace	.040	1.502 ^b	1.000	36.000	.228
	Wilks' Lambda	.960	1.502 ^b	1.000	36.000	.228
	Hotelling's Trace	.042	1.502 ^b	1.000	36.000	.228
	Roy's Largest Root	.042	1.502 ^b	1.000	36.000	.228

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: RG_SIDE

b. Exact statistic

Table 46: Univariate analysis for RA– side effect

Effect		Value	F	Hypothesis df	Error df	Sig.
RA_SIDE	Pillai's Trace	.069	2.681 ^b	1.000	36.000	.110
	Wilks' Lambda	.931	2.681 ^b	1.000	36.000	.110
	Hotelling's Trace	.074	2.681 ^b	1.000	36.000	.110
	Roy's Largest Root	.074	2.681 ^b	1.000	36.000	.110
RA_SIDE * GENDER	Pillai's Trace	.012	.426 ^b	1.000	36.000	.518
	Wilks' Lambda	.988	.426 ^b	1.000	36.000	.518
	Hotelling's Trace	.012	.426 ^b	1.000	36.000	.518
	Roy's Largest Root	.012	.426 ^b	1.000	36.000	.518
RA_SIDE * FATIGUE	Pillai's Trace	.025	.914 ^b	1.000	36.000	.345
	Wilks' Lambda	.975	.914 ^b	1.000	36.000	.345
	Hotelling's Trace	.025	.914 ^b	1.000	36.000	.345
	Roy's Largest Root	.025	.914 ^b	1.000	36.000	.345
RA_SIDE * GENDER * FATIGUE	Pillai's Trace	.013	.463 ^b	1.000	36.000	.501
	Wilks' Lambda	.987	.463 ^b	1.000	36.000	.501
	Hotelling's Trace	.013	.463 ^b	1.000	36.000	.501
	Roy's Largest Root	.013	.463 ^b	1.000	36.000	.501

a. Design: Intercept + GENDER + FATIGUE + GENDER * FATIGUE
Within Subjects Design: RA_SIDE

b. Exact statistic

Appendix K: Multivariate analysis for FRP parameters - fatigue & gender effect

Table 47: Multivariate analysis for FRP parameters – fatigue, gender and their interaction effect

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	FRR	26.729 ^a	3	8.910	19.968	.000
	ONSET	.161 ^b	3	.054	50.000	.000
	OFFSET	.023 ^c	3	.008	16.639	.000
	T1	45228.108 ^d	3	15076.036	29.491	.000
	T2	3812.261 ^e	3	1270.754	32.316	.000
	EXPANSION	74615.174 ^f	3	24871.725	47.168	.000
Intercept	FRR	673.913	1	673.913	1510.322	.000
	ONSET	21.838	1	21.838	20408.193	.000
	OFFSET	35.744	1	35.744	78298.616	.000
	T1	639626.251	1	639626.251	1251.197	.000
	T2	34810.000	1	34810.000	885.233	.000
	EXPANSION	972868.084	1	972868.084	1844.991	.000
GENDER	FRR	1.816	1	1.816	4.069	.051
	ONSET	.002	1	.002	1.535	.223
	OFFSET	7.797E-005	1	7.797E-005	.171	.682
	T1	775.867	1	775.867	1.518	.226
	T2	13.611	1	13.611	.346	.560
	EXPANSION	583.951	1	583.951	1.107	.300
FATIGUE	FRR	24.288	1	24.288	54.432	.000
	ONSET	.159	1	.159	148.262	.000
	OFFSET	.023	1	.023	49.371	.000
	T1	44277.934	1	44277.934	86.614	.000
	T2	3783.025	1	3783.025	96.204	.000
	EXPANSION	73945.667	1	73945.667	140.234	.000
GENDER * FATIGUE	FRR	.625	1	.625	1.402	.244
	ONSET	.000	1	.000	.204	.654
	OFFSET	.000	1	.000	.374	.545
	T1	174.306	1	174.306	.341	.563
	T2	15.625	1	15.625	.397	.532
	EXPANSION	85.556	1	85.556	.162	.689
Error	FRR	16.063	36	.446		
	ONSET	.039	36	.001		
	OFFSET	.016	36	.000		
	T1	18403.614	36	511.211		
	T2	1415.628	36	39.323		
	EXPANSION	18982.881	36	527.302		
Total	FRR	716.705	40			
	ONSET	22.037	40			
	OFFSET	35.784	40			
	T1	703257.972	40			
	T2	40037.889	40			
	EXPANSION	1066466.139	40			
Corrected Total	FRR	42.792	39			
	ONSET	.199	39			
	OFFSET	.039	39			
	T1	63631.722	39			
	T2	5227.889	39			
	EXPANSION	93598.055	39			

Appendix L: Multivariate analysis for SP parameters– fatigue & gender effects

Table 48: Multivariate analysis for SP parameters – fatigue, gender and their interaction effect

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	OD	13864.820 ^a	3	4621.607	6.834	.001
	TTP	90683.759 ^b	3	30227.920	14.367	.000
	PTP	79840.819 ^c	3	26613.606	13.602	.000
	RA	11.651 ^d	3	3.884	5.214	.004
	RG	1.432E-005 ^e	3	4.774E-006	6.162	.002
Intercept	OD	486257.627	1	486257.627	719.030	.000
	TTP	3098286.075	1	3098286.075	1472.594	.000
	PTP	715937.049	1	715937.049	365.915	.000
	RA	188.575	1	188.575	253.155	.000
	RG	.000	1	.000	236.139	.000
GENDER	OD	1058.327	1	1058.327	1.565	.219
	TTP	688.485	1	688.485	.327	.571
	PTP	415.380	1	415.380	.212	.648
	RA	8.990	1	8.990	12.069	.001
	RG	1.118E-005	1	1.118E-005	14.433	.001
FATIGUE	OD	12174.866	1	12174.866	18.003	.000
	TTP	89222.193	1	89222.193	42.407	.000
	PTP	78960.996	1	78960.996	40.357	.000
	RA	2.655	1	2.655	3.564	.067
	RG	2.730E-006	1	2.730E-006	3.523	.069
GENDER * FATIGUE	OD	631.628	1	631.628	.934	.340
	TTP	773.081	1	773.081	.367	.548
	PTP	464.442	1	464.442	.237	.629
	RA	.006	1	.006	.008	.929
	RG	4.101E-007	1	4.101E-007	.529	.472
Error	OD	24345.671	36	676.269		
	TTP	75742.719	36	2103.964		
	PTP	70436.417	36	1956.567		
	RA	26.816	36	.745		
	RG	2.789E-005	36	7.748E-007		
Total	OD	524468.117	40			
	TTP	3264712.553	40			
	PTP	866214.285	40			
	RA	227.042	40			
	RG	.000	40			
Corrected Total	OD	38210.491	39			
	TTP	166426.477	39			
	PTP	150277.236	39			
	RA	38.467	39			
	RG	4.222E-005	39			

a. R Squared = .363 (Adjusted R Squared = .310)

b. R Squared = .545 (Adjusted R Squared = .507)

c. R Squared = .531 (Adjusted R Squared = .492)

d. R Squared = .303 (Adjusted R Squared = .245)

e. R Squared = .339 (Adjusted R Squared = .284)

Table 49: Multivariate analysis for stiffness – fatigue, gender and their interaction effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power ^c
Corrected Model	Intrinsic_stiffness	227512.442 ^a	3	75837.481	9.337	.000	28.011	.993
	Effective_stiffness	1042062.02 ^b	3	347354.008	22.942	.000	68.827	1.000
Intercept	Intrinsic_stiffness	32474157.15	1	32474157.15	3998.208	.000	3998.208	1.000
	Effective_stiffness	62059218.47	1	62059218.47	4098.966	.000	4098.966	1.000
Gender	Intrinsic_stiffness	3725.865	1	3725.865	.459	.503	.459	.101
	Effective_stiffness	25378.053	1	25378.053	1.676	.204	1.676	.243
Fatigue	Intrinsic_stiffness	223322.923	1	223322.923	27.495	.000	27.495	.999
	Effective_stiffness	1011970.278	1	1011970.278	66.840	.000	66.840	1.000
Gender * Fatigue	Intrinsic_stiffness	463.653	1	463.653	.057	.813	.057	.056
	Effective_stiffness	4713.694	1	4713.694	.311	.580	.311	.084
Error	Intrinsic_stiffness	292398.434	36	8122.179				
	Effective_stiffness	545047.626	36	15140.212				
Total	Intrinsic_stiffness	32994068.02	40					
	Effective_stiffness	63646328.12	40					
Corrected Total	Intrinsic_stiffness	519910.876	39					
	Effective_stiffness	1587109.650	39					

a. R Squared = .438 (Adjusted R Squared = .391)

b. R Squared = .657 (Adjusted R Squared = .628)

c. Computed using alpha = .05

Appendix M: Statistical analysis for recovery data

Table 50: Normality test for FRP recovery data

	Time	Kolmogorov-Smirnov ^b			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Residual for FRR	1 *	.124	20	.200 [*]	.979	20	.922
	2	.107	20	.200 [*]	.973	20	.824
	3	.106	20	.200 [*]	.976	20	.866
	4	.102	20	.200 [*]	.981	20	.949
	5	.130	20	.200 [*]	.978	20	.905
	6	.127	20	.200 [*]	.977	20	.896
Residual for Onset	1	.213	20	.018	.914	20	.077
	2	.144	20	.200 [*]	.934	20	.186
	3	.173	20	.120	.916	20	.082
	4	.236	20	.005	.897	20	.036
	5	.248	20	.002	.912	20	.069
	6	.227	20	.008	.906	20	.053
Residual for Offset	1	.121	20	.200 [*]	.986	20	.987
	2	.135	20	.200 [*]	.956	20	.473
	3	.087	20	.200 [*]	.966	20	.666
	4	.108	20	.200 [*]	.955	20	.456
	5	.128	20	.200 [*]	.984	20	.972
	6	.107	20	.200 [*]	.985	20	.982
Residual for T1	1	.182	20	.080	.813	20	.001
	2	.137	20	.200 [*]	.970	20	.753
	3	.215	20	.016	.824	20	.002
	4	.168	20	.141	.774	20	.000
	5	.191	20	.055	.810	20	.001
	6	.188	20	.062	.810	20	.001
Residual for T2	1	.160	20	.192	.939	20	.225
	2	.102	20	.200 [*]	.965	20	.653
	3	.153	20	.200 [*]	.924	20	.119
	4	.148	20	.200 [*]	.907	20	.056
	5	.145	20	.200 [*]	.935	20	.189
	6	.159	20	.200 [*]	.933	20	.173
Residual for Expansion	1	.156	20	.200 [*]	.839	20	.003
	2	.100	20	.200 [*]	.973	20	.810
	3	.194	20	.047	.754	20	.000
	4	.189	20	.060	.804	20	.001
	5	.172	20	.124	.833	20	.003
	6	.170	20	.130	.838	20	.003

* *Time 1 = Pre-fatigue* *Time 2 = Post-fatigue* *Time 3 = Recovery 15*
Time 4 = Recovery 30 *Time 5 = Recovery 45* *Time 6 = Recovery 60*

Table 51: Levene's test for FRP parameters recovery data

		Levene Statistic	df1	df2	Sig.
FRR	Based on Mean	.379	1	118	.539
	Based on Median	.558	1	118	.457
	Based on Median and with adjusted df	.558	1	117.579	.457
	Based on trimmed mean	.405	1	118	.526
Onset	Based on Mean	.096	1	118	.757
	Based on Median	.013	1	118	.910
	Based on Median and with adjusted df	.013	1	117.490	.910
	Based on trimmed mean	.040	1	118	.841
Offset	Based on Mean	.482	1	118	.489
	Based on Median	.505	1	118	.479
	Based on Median and with adjusted df	.505	1	117.406	.479
	Based on trimmed mean	.571	1	118	.451
T1	Based on Mean	4.018	1	118	.047
	Based on Median	3.042	1	118	.084
	Based on Median and with adjusted df	3.042	1	112.460	.084
	Based on trimmed mean	3.312	1	118	.071
T2	Based on Mean	.652	1	118	.421
	Based on Median	1.493	1	118	.224
	Based on Median and with adjusted df	1.493	1	117.843	.224
	Based on trimmed mean	.986	1	118	.323
Expansion	Based on Mean	2.684	1	118	.104
	Based on Median	2.175	1	118	.143
	Based on Median and with adjusted df	2.175	1	116.517	.143
	Based on trimmed mean	2.276	1	118	.134

Table 52: Post hoc pairwise comparison for FRP parameters recovery data

Dependent Variable	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
						Lower Bound	Upper Bound
FRR	Pre	Post	1.558 [*]	.228	.000	1.107	2.010
		Recv 15	.078	.228	.733	-.374	.529
		Recv 30	.017	.228	.939	-.434	.469
		Recv 45	-.006	.228	.979	-.457	.445
		Recv 60	-.010	.228	.967	-.461	.442
	Post	Pre	-1.558 [*]	.228	.000	-2.010	-1.107
		Recv 15	-1.481 [*]	.228	.000	-1.932	-1.029
		Recv 30	-1.541 [*]	.228	.000	-1.992	-1.090
		Recv 45	-1.565 [*]	.228	.000	-2.016	-1.113
		Recv 60	-1.568 [*]	.228	.000	-2.019	-1.117
	Recv 15	Pre	-.078	.228	.733	-.529	.374
		Post	1.481 [*]	.228	.000	1.029	1.932
		Recv 30	-.060	.228	.791	-.512	.391
		Recv 45	-.084	.228	.713	-.535	.367
		Recv 60	-.087	.228	.702	-.539	.364
	Recv 30	Pre	-.017	.228	.939	-.469	.434
		Post	1.541 [*]	.228	.000	1.090	1.992
		Recv 15	.060	.228	.791	-.391	.512
		Recv 45	-.023	.228	.918	-.475	.428
		Recv 60	-.027	.228	.906	-.478	.424
	Recv 45	Pre	.006	.228	.979	-.445	.457
		Post	1.565 [*]	.228	.000	1.113	2.016
		Recv 15	.084	.228	.713	-.367	.535
		Recv 30	.023	.228	.918	-.428	.475
		Recv 60	-.003	.228	.988	-.455	.448
	Recv 60	Pre	.010	.228	.967	-.442	.461
		Post	1.568 [*]	.228	.000	1.117	2.019
		Recv 15	.087	.228	.702	-.364	.539
		Recv 30	.027	.228	.906	-.424	.478
		Recv 45	.003	.228	.988	-.448	.455
Onset	Pre	Post	.126 [*]	.008	.000	.110	.142
		Recv 15	.028 [*]	.008	.001	.011	.044
		Recv 30	.014	.008	.081	-.002	.030
		Recv 45	.000	.008	.981	-.016	.016
		Recv 60	-.001	.008	.947	-.017	.016
	Post	Pre	-.126 [*]	.008	.000	-.142	-.110
		Recv 15	-.098 [*]	.008	.000	-.115	-.082
		Recv 30	-.112 [*]	.008	.000	-.128	-.095
		Recv 45	-.126 [*]	.008	.000	-.142	-.110
		Recv 60	-.126 [*]	.008	.000	-.143	-.110
	Recv 15	Pre	-.028 [*]	.008	.001	-.044	-.011
		Post	.098 [*]	.008	.000	.082	.115
		Recv 30	-.013	.008	.107	-.029	.003
		Recv 45	-.027 [*]	.008	.001	-.044	-.011
		Recv 60	-.028 [*]	.008	.001	-.044	-.012
	Recv 30	Pre	-.014	.008	.081	-.030	.002
		Post	.112 [*]	.008	.000	.095	.128
		Recv 15	.013	.008	.107	-.003	.029
		Recv 45	-.014	.008	.085	-.030	.002
		Recv 60	-.015	.008	.070	-.031	.001
	Recv 45	Pre	.000	.008	.981	-.016	.016
		Post	.126 [*]	.008	.000	.110	.142
		Recv 15	.027 [*]	.008	.001	.011	.044
		Recv 30	.014	.008	.085	-.002	.030
		Recv 60	-.001	.008	.928	-.017	.015
	Recv 60	Pre	.001	.008	.947	-.016	.017
		Post	.126 [*]	.008	.000	.110	.143
		Recv 15	.028 [*]	.008	.001	.012	.044
		Recv 30	.015	.008	.070	-.001	.031
		Recv 45	.001	.008	.928	-.015	.017

Dependent Variable	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
						Lower Bound	Upper Bound
Offset	Pre	Post	.047 [*]	.005	.000	.038	.057
		Recv 15	.007	.005	.163	-.003	.017
		Recv 30	.003	.005	.511	-.007	.013
		Recv 45	7.463E-005	.005	.988	-.010	.010
		Recv 60	-.001	.005	.895	-.011	.009
	Post	Pre	-.047 [*]	.005	.000	-.057	-.038
		Recv 15	-.040 [*]	.005	.000	-.050	-.031
		Recv 30	-.044 [*]	.005	.000	-.054	-.034
		Recv 45	-.047 [*]	.005	.000	-.057	-.037
		Recv 60	-.048 [*]	.005	.000	-.058	-.038
	Recv 15	Pre	-.007	.005	.163	-.017	.003
		Post	.040 [*]	.005	.000	.031	.050
		Recv 30	-.004	.005	.458	-.014	.006
		Recv 45	-.007	.005	.168	-.017	.003
		Recv 60	-.008	.005	.127	-.018	.002
	Recv 30	Pre	-.003	.005	.511	-.013	.007
		Post	.044 [*]	.005	.000	.034	.054
		Recv 15	.004	.005	.458	-.006	.014
		Recv 45	-.003	.005	.521	-.013	.007
		Recv 60	-.004	.005	.430	-.014	.006
	Recv 45	Pre	-7.463E-005	.005	.988	-.010	.010
		Post	.047 [*]	.005	.000	.037	.057
		Recv 15	.007	.005	.168	-.003	.017
		Recv 30	.003	.005	.521	-.007	.013
		Recv 60	-.001	.005	.883	-.011	.009
	Recv 60	Pre	.001	.005	.895	-.009	.011
		Post	.048 [*]	.005	.000	.038	.058
		Recv 15	.008	.005	.127	-.002	.018
		Recv 30	.004	.005	.430	-.006	.014
		Recv 45	.001	.005	.883	-.009	.011
T1	Pre	Post	-66.542 [*]	5.537	.000	-77.516	-55.567
		Recv 15	-6.175	5.537	.267	-17.150	4.800
		Recv 30	-2.175	5.537	.695	-13.150	8.800
		Recv 45	.033	5.537	.995	-10.941	11.008
		Recv 60	.175	5.537	.975	-10.800	11.150
	Post	Pre	66.542 [*]	5.537	.000	55.567	77.516
		Recv 15	60.367 [*]	5.537	.000	49.392	71.341
		Recv 30	64.367 [*]	5.537	.000	53.392	75.341
		Recv 45	66.575 [*]	5.537	.000	55.600	77.550
		Recv 60	66.717 [*]	5.537	.000	55.742	77.691
	Recv 15	Pre	6.175	5.537	.267	-4.800	17.150
		Post	-60.367 [*]	5.537	.000	-71.341	-49.392
		Recv 30	4.000	5.537	.472	-6.975	14.975
		Recv 45	6.208	5.537	.265	-4.766	17.183
		Recv 60	6.350	5.537	.254	-4.625	17.325
	Recv 30	Pre	2.175	5.537	.695	-8.800	13.150
		Post	-64.367 [*]	5.537	.000	-75.341	-53.392
		Recv 15	-4.000	5.537	.472	-14.975	6.975
		Recv 45	2.208	5.537	.691	-8.766	13.183
		Recv 60	2.350	5.537	.672	-8.625	13.325
	Recv 45	Pre	-.033	5.537	.995	-11.008	10.941
		Post	-66.575 [*]	5.537	.000	-77.550	-55.600
		Recv 15	-6.208	5.537	.265	-17.183	4.766
		Recv 30	-2.208	5.537	.691	-13.183	8.766
		Recv 60	.142	5.537	.980	-10.833	11.116
	Recv 60	Pre	-.175	5.537	.975	-11.150	10.800
		Post	-66.717 [*]	5.537	.000	-77.691	-55.742
		Recv 15	-6.350	5.537	.254	-17.325	4.625
		Recv 30	-2.350	5.537	.672	-13.325	8.625
		Recv 45	-.142	5.537	.980	-11.116	10.833

Dependent Variable	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
						Lower Bound	Upper Bound
T2	Pre	Post	-19.450 [*]	1.393	.000	-22.211	-16.689
		Recv 15	-1.608	1.393	.251	-4.369	1.152
		Recv 30	-.792	1.393	.571	-3.552	1.969
		Recv 45	-.008	1.393	.995	-2.769	2.752
		Recv 60	.175	1.393	.900	-2.586	2.936
	Post	Pre	19.450 [*]	1.393	.000	16.689	22.211
		Recv 15	17.842 [*]	1.393	.000	15.081	20.602
		Recv 30	18.658 [*]	1.393	.000	15.898	21.419
		Recv 45	19.442 [*]	1.393	.000	16.681	22.202
		Recv 60	19.625 [*]	1.393	.000	16.864	22.386
	Recv 15	Pre	1.608	1.393	.251	-1.152	4.369
		Post	-17.842 [*]	1.393	.000	-20.602	-15.081
		Recv 30	.817	1.393	.559	-1.944	3.577
		Recv 45	1.600	1.393	.253	-1.161	4.361
		Recv 60	1.783	1.393	.203	-.977	4.544
	Recv 30	Pre	.792	1.393	.571	-1.969	3.552
		Post	-18.658 [*]	1.393	.000	-21.419	-15.898
		Recv 15	-.817	1.393	.559	-3.577	1.944
		Recv 45	.783	1.393	.575	-1.977	3.544
		Recv 60	.967	1.393	.489	-1.794	3.727
	Recv 45	Pre	.008	1.393	.995	-2.752	2.769
		Post	-19.442 [*]	1.393	.000	-22.202	-16.681
		Recv 15	-1.600	1.393	.253	-4.361	1.161
		Recv 30	-.783	1.393	.575	-3.544	1.977
		Recv 60	.183	1.393	.896	-2.577	2.944
	Recv 60	Pre	-.175	1.393	.900	-2.936	2.586
		Post	-19.625 [*]	1.393	.000	-22.386	-16.864
		Recv 15	-1.783	1.393	.203	-4.544	.977
		Recv 30	-.967	1.393	.489	-3.727	1.794
		Recv 45	-.183	1.393	.896	-2.944	2.577
Expansion	Pre	Post	-85.992 [*]	5.691	.000	-97.272	-74.712
		Recv 15	-7.967	5.691	.164	-19.247	3.313
		Recv 30	-2.383	5.691	.676	-13.663	8.897
		Recv 45	.025	5.691	.997	-11.255	11.305
		Recv 60	.350	5.691	.951	-10.930	11.630
	Post	Pre	85.992 [*]	5.691	.000	74.712	97.272
		Recv 15	78.025 [*]	5.691	.000	66.745	89.305
		Recv 30	83.608 [*]	5.691	.000	72.328	94.888
		Recv 45	86.017 [*]	5.691	.000	74.737	97.297
		Recv 60	86.342 [*]	5.691	.000	75.062	97.622
	Recv 15	Pre	7.967	5.691	.164	-3.313	19.247
		Post	-78.025 [*]	5.691	.000	-89.305	-66.745
		Recv 30	5.583	5.691	.329	-5.697	16.863
		Recv 45	7.992	5.691	.163	-3.288	19.272
		Recv 60	8.317	5.691	.147	-2.963	19.597
	Recv 30	Pre	2.383	5.691	.676	-8.897	13.663
		Post	-83.608 [*]	5.691	.000	-94.888	-72.328
		Recv 15	-5.583	5.691	.329	-16.863	5.697
		Recv 45	2.408	5.691	.673	-8.872	13.688
		Recv 60	2.733	5.691	.632	-8.547	14.013
	Recv 45	Pre	-.025	5.691	.997	-11.305	11.255
		Post	-86.017 [*]	5.691	.000	-97.297	-74.737
		Recv 15	-7.992	5.691	.163	-19.272	3.288
		Recv 30	-2.408	5.691	.673	-13.688	8.872
		Recv 60	.325	5.691	.955	-10.955	11.605
	Recv 60	Pre	-.350	5.691	.951	-11.630	10.930
		Post	-86.342 [*]	5.691	.000	-97.622	-75.062
		Recv 15	-8.317	5.691	.147	-19.597	2.963
		Recv 30	-2.733	5.691	.632	-14.013	8.547
		Recv 45	-.325	5.691	.955	-11.605	10.955

Table 53: Multivariate analysis for FRP recovery data – gender effect

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig. ^b	Interval for Difference ^b	
						Lower Bound	Upper Bound
FRR	Male	Female	-.008	.010	.445	-.028	.013
	Female	Male	.008	.010	.445	-.013	.028
Onset	Male	Female	.021	.014	.153	-.008	.050
	Female	Male	-.021	.014	.153	-.050	.008
Offset	Male	Female	.018	.018	.302	-.017	.053
	Female	Male	-.018	.018	.302	-.053	.017
T1	Male	Female	-6.145E-06	.011	1.000	-.023	.023
	Female	Male	6.145E-06	.011	1.000	-.023	.023
T2	Male	Female	.026 [*]	.011	.171	.005	.047
	Female	Male	-.026 [*]	.011	.171	-.047	-.005
Expansion	Male	Female	.002	.011	.845	-.019	.023
	Female	Male	-.002	.011	.845	-.023	.019

Table 54: Multivariate analysis for FRP recovery data –fatigue, gender and their interaction effects

Effect		Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power ^d
Intercept	Pillai's Trace	1.000	34722.978 ^b	6.000	67.000	.000	208337.870	1.000
	Wilks' Lambda	.000	34722.978 ^b	6.000	67.000	.000	208337.870	1.000
	Hotelling's Trace	3109.520	34722.978 ^b	6.000	67.000	.000	208337.870	1.000
	Roy's Largest Root	3109.520	34722.978 ^b	6.000	67.000	.000	208337.870	1.000
Gender	Pillai's Trace	.116	1.460 ^b	6.000	67.000	.206	8.758	.530
	Wilks' Lambda	.884	1.460 ^b	6.000	67.000	.206	8.758	.530
	Hotelling's Trace	.131	1.460 ^b	6.000	67.000	.206	8.758	.530
	Roy's Largest Root	.131	1.460 ^b	6.000	67.000	.206	8.758	.530
Time	Pillai's Trace	.948	5.311	18.000	207.000	.000	95.598	1.000
	Wilks' Lambda	.125	11.456	18.000	189.990	.000	189.892	1.000
	Hotelling's Trace	6.414	23.400	18.000	197.000	.000	421.198	1.000
	Roy's Largest Root	6.323	72.715 ^c	6.000	69.000	.000	436.289	1.000
Gender * Time	Pillai's Trace	.229	.950	18.000	207.000	.519	17.099	.672
	Wilks' Lambda	.782	.959	18.000	189.990	.509	16.226	.639
	Hotelling's Trace	.265	.966	18.000	197.000	.500	17.391	.680
	Roy's Largest Root	.197	2.264 ^c	6.000	69.000	.047	13.586	.755

Table 55: Normality test for SP parameters recovery data

	Time	Kolmogorov-Smirnov ^b			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Residual for OD	1	.181	20	.084	.922	20	.107
	2	.128	20	.200 [*]	.951	20	.376
	3	.190	20	.056	.915	20	.078
	4	.204	20	.029	.914	20	.075
	5	.190	20	.055	.920	20	.099
	6	.187	20	.065	.921	20	.102
Residual for TTP	1	.157	20	.200 [*]	.921	20	.102
	2	.087	20	.200 [*]	.968	20	.720
	3	.130	20	.200 [*]	.943	20	.276
	4	.108	20	.200 [*]	.946	20	.307
	5	.157	20	.200 [*]	.922	20	.108
	6	.159	20	.199	.922	20	.108
Residual for PTP	1	.130	20	.200 [*]	.959	20	.531
	2	.119	20	.200 [*]	.955	20	.457
	3	.166	20	.148	.958	20	.500
	4	.128	20	.200 [*]	.961	20	.559
	5	.129	20	.200 [*]	.960	20	.538
	6	.128	20	.200 [*]	.960	20	.540
Residual for Stiffness	1	.111	20	.200 [*]	.958	20	.506
	2	.102	20	.200 [*]	.967	20	.695
	3	.118	20	.200 [*]	.962	20	.577
	4	.121	20	.200 [*]	.957	20	.483
	5	.105	20	.200 [*]	.959	20	.516
	6	.110	20	.200 [*]	.957	20	.489

Table 56: Leven's test for SP parameters recovery data

	F	df1	df2	Sig.
OD	.831	11	108	.609
TTP	.261	11	108	.991
PTP	1.049	11	108	.409
Stiffness	.057	11	108	1.000

Table 57: Post hoc pairwise comparison for SP parameters recovery data

Dependent Variable	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
						Lower Bound	Upper Bound
OD	Pre	Post	-34.800 [*]	7.245	.000	-49.161	-20.439
		Recv 15	-3.642	7.245	.616	-18.003	10.719
		Recv 30	-1.442	7.245	.843	-15.803	12.919
		Recv 45	-.400	7.245	.956	-14.761	13.961
		Recv 60	.092	7.245	.990	-14.269	14.453
	Post	Pre	34.800 [*]	7.245	.000	20.439	49.161
		Recv 15	31.158 [*]	7.245	.000	16.797	45.519
		Recv 30	33.358 [*]	7.245	.000	18.997	47.719
		Recv 45	34.400 [*]	7.245	.000	20.039	48.761
		Recv 60	34.892 [*]	7.245	.000	20.531	49.253
	Recv 15	Pre	3.642	7.245	.616	-10.719	18.003
		Post	-31.158 [*]	7.245	.000	-45.519	-16.797
		Recv 30	2.200	7.245	.762	-12.161	16.561
		Recv 45	3.242	7.245	.655	-11.119	17.603
		Recv 60	3.733	7.245	.607	-10.628	18.094
	Recv 30	Pre	1.442	7.245	.843	-12.919	15.803
		Post	-33.358 [*]	7.245	.000	-47.719	-18.997
		Recv 15	-2.200	7.245	.762	-16.561	12.161
		Recv 45	1.042	7.245	.886	-13.319	15.403
		Recv 60	1.533	7.245	.833	-12.828	15.894
	Recv 45	Pre	.400	7.245	.956	-13.961	14.761
		Post	-34.400 [*]	7.245	.000	-48.761	-20.039
		Recv 15	-3.242	7.245	.655	-17.603	11.119
		Recv 30	-1.042	7.245	.886	-15.403	13.319
		Recv 60	.492	7.245	.946	-13.869	14.853
	Recv 60	Pre	-.092	7.245	.990	-14.453	14.269
		Post	-34.892 [*]	7.245	.000	-49.253	-20.531
		Recv 15	-3.733	7.245	.607	-18.094	10.628
		Recv 30	-1.533	7.245	.833	-15.894	12.828
		Recv 45	-.492	7.245	.946	-14.853	13.869
TTP	Pre	Post	-94.458 [*]	13.419	.000	-121.057	-67.859
		Recv 15	-11.500	13.419	.393	-38.099	15.099
		Recv 30	-5.933	13.419	.659	-32.532	20.666
		Recv 45	-1.208	13.419	.928	-27.807	25.391
		Recv 60	.667	13.419	.960	-25.932	27.266
	Post	Pre	94.458 [*]	13.419	.000	67.859	121.057
		Recv 15	82.958 [*]	13.419	.000	56.359	109.557
		Recv 30	88.525 [*]	13.419	.000	61.926	115.124
		Recv 45	93.250 [*]	13.419	.000	66.651	119.849
		Recv 60	95.125 [*]	13.419	.000	68.526	121.724
	Recv 15	Pre	11.500	13.419	.393	-15.099	38.099
		Post	-82.958 [*]	13.419	.000	-109.557	-56.359
		Recv 30	5.567	13.419	.679	-21.032	32.166
		Recv 45	10.292	13.419	.445	-16.307	36.891
		Recv 60	12.167	13.419	.367	-14.432	38.766
	Recv 30	Pre	5.933	13.419	.659	-20.666	32.532
		Post	-88.525 [*]	13.419	.000	-115.124	-61.926
		Recv 15	-5.567	13.419	.679	-32.166	21.032
		Recv 45	4.725	13.419	.725	-21.874	31.324
		Recv 60	6.600	13.419	.624	-19.999	33.199
	Recv 45	Pre	1.208	13.419	.928	-25.391	27.807
		Post	-93.250 [*]	13.419	.000	-119.849	-66.651
		Recv 15	-10.292	13.419	.445	-36.891	16.307
		Recv 30	-4.725	13.419	.725	-31.324	21.874
		Recv 60	1.875	13.419	.889	-24.724	28.474
	Recv 60	Pre	-.667	13.419	.960	-27.266	25.932
		Post	-95.125 [*]	13.419	.000	-121.724	-68.526
		Recv 15	-12.167	13.419	.367	-38.766	14.432
		Recv 30	-6.600	13.419	.624	-33.199	19.999
		Recv 45	-1.875	13.419	.889	-28.474	24.724

Dependent Variable	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig. ^b	95% Confidence Interval for Difference ^b	
						Lower Bound	Upper Bound
PTP	Pre	Post	-88.867 [*]	12.589	.000	-113.821	-63.913
		Recv 15	-6.617	12.589	.600	-31.571	18.337
		Recv 30	-2.633	12.589	.835	-27.587	22.321
		Recv 45	-.108	12.589	.993	-25.062	24.846
		Recv 60	.800	12.589	.949	-24.154	25.754
	Post	Pre	88.867 [*]	12.589	.000	63.913	113.821
		Recv 15	82.250 [*]	12.589	.000	57.296	107.204
		Recv 30	86.233 [*]	12.589	.000	61.279	111.187
		Recv 45	88.758 [*]	12.589	.000	63.804	113.712
		Recv 60	89.667 [*]	12.589	.000	64.713	114.621
	Recv 15	Pre	6.617	12.589	.600	-18.337	31.571
		Post	-82.250 [*]	12.589	.000	-107.204	-57.296
		Recv 30	3.983	12.589	.752	-20.971	28.937
		Recv 45	6.508	12.589	.606	-18.446	31.462
		Recv 60	7.417	12.589	.557	-17.537	32.371
	Recv 30	Pre	2.633	12.589	.835	-22.321	27.587
		Post	-86.233 [*]	12.589	.000	-111.187	-61.279
		Recv 15	-3.983	12.589	.752	-28.937	20.971
		Recv 45	2.525	12.589	.841	-22.429	27.479
		Recv 60	3.433	12.589	.786	-21.521	28.387
	Recv 45	Pre	.108	12.589	.993	-24.846	25.062
		Post	-88.758 [*]	12.589	.000	-113.712	-63.804
		Recv 15	-6.508	12.589	.606	-31.462	18.446
		Recv 30	-2.525	12.589	.841	-27.479	22.429
		Recv 60	.908	12.589	.943	-24.046	25.862
	Recv 60	Pre	-.800	12.589	.949	-25.754	24.154
		Post	-89.667 [*]	12.589	.000	-114.621	-64.713
		Recv 15	-7.417	12.589	.557	-32.371	17.537
		Recv 30	-3.433	12.589	.786	-28.387	21.521
		Recv 45	-.908	12.589	.943	-25.862	24.046
Stiffness	Pre	Post	150.526 [*]	27.721	.000	95.578	205.474
		Recv 15	20.893	27.721	.453	-34.055	75.841
		Recv 30	11.050	27.721	.691	-43.898	65.997
		Recv 45	1.389	27.721	.960	-53.558	56.337
		Recv 60	-1.086	27.721	.969	-56.034	53.862
	Post	Pre	-150.526 [*]	27.721	.000	-205.474	-95.578
		Recv 15	-129.633 [*]	27.721	.000	-184.581	-74.685
		Recv 30	-139.476 [*]	27.721	.000	-194.424	-84.529
		Recv 45	-149.137 [*]	27.721	.000	-204.085	-94.189
		Recv 60	-151.612 [*]	27.721	.000	-206.560	-96.665
	Recv 15	Pre	-20.893	27.721	.453	-75.841	34.055
		Post	129.633 [*]	27.721	.000	74.685	184.581
		Recv 30	-9.844	27.721	.723	-64.791	45.104
		Recv 45	-19.504	27.721	.483	-74.452	35.444
		Recv 60	-21.979	27.721	.430	-76.927	32.968
	Recv 30	Pre	-11.050	27.721	.691	-65.997	43.898
		Post	139.476 [*]	27.721	.000	84.529	194.424
		Recv 15	9.844	27.721	.723	-45.104	64.791
		Recv 45	-9.660	27.721	.728	-64.608	45.288
		Recv 60	-12.136	27.721	.662	-67.084	42.812
	Recv 45	Pre	-1.389	27.721	.960	-56.337	53.558
		Post	149.137 [*]	27.721	.000	94.189	204.085
		Recv 15	19.504	27.721	.483	-35.444	74.452
		Recv 30	9.660	27.721	.728	-45.288	64.608
		Recv 60	-2.476	27.721	.929	-57.423	52.472
	Recv 60	Pre	1.086	27.721	.969	-53.862	56.034
		Post	151.612 [*]	27.721	.000	96.665	206.560
		Recv 15	21.979	27.721	.430	-32.968	76.927
		Recv 30	12.136	27.721	.662	-42.812	67.084
		Recv 45	2.476	27.721	.929	-52.472	57.423

Table 58: Multivariate analysis for SP parameters recovery data: fatigue, gender and their interaction effect

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power ^e
Corrected Model	OD	20992.769 ^a	11	1908.434	3.636	.000	39.993	.995
	TTP	141168.041 ^b	11	12833.458	7.127	.000	78.396	1.000
	PTP	128218.895 ^c	11	11656.263	7.355	.000	80.902	1.000
	Stiffness	369925.853 ^d	11	33629.623	4.376	.000	48.139	.999
Intercept	OD	1188394.861	1	1188394.861	2264.002	.000	2264.002	1.000
	TTP	7489337.126	1	7489337.126	4159.094	.000	4159.094	1.000
	PTP	1337846.419	1	1337846.419	844.134	.000	844.134	1.000
	Stiffness	107228173.0	1	107228173.0	13953.778	.000	13953.778	1.000
Gender	OD	787.969	1	787.969	1.501	.223	1.501	.229
	TTP	185.008	1	185.008	.103	.749	.103	.062
	PTP	103.602	1	103.602	.065	.799	.065	.057
	Stiffness	16281.677	1	16281.677	2.119	.148	2.119	.303
Time	OD	19146.404	5	3829.281	7.295	.000	36.476	.999
	TTP	139697.199	5	27939.440	15.516	.000	77.579	1.000
	PTP	127334.249	5	25466.850	16.069	.000	80.343	1.000
	Stiffness	353044.662	5	70608.932	9.188	.000	45.942	1.000
Gender * Time	OD	1058.397	5	211.679	.403	.846	2.016	.152
	TTP	1285.833	5	257.167	.143	.982	.714	.082
	PTP	781.044	5	156.209	.099	.992	.493	.071
	Stiffness	599.514	5	119.903	.016	1.000	.078	.053

Table 59: Multivariate analysis for SP parameters recovery data: gender effect

Dependent Variable	(I) Gender	(J) Gender	Mean Difference (I-J)	Std. Error	Sig. ^a	95% Confidence Interval for Difference ^a	
						Lower Bound	Upper Bound
OD	Male	Female	.018	.010	.084	-.002	.039
	Female	Male	-.018	.010	.084	-.039	.002
TTP	Male	Female	-.002	.011	.853	-.024	.020
	Female	Male	.002	.011	.853	-.020	.024
PTP	Male	Female	.004	.010	.724	-.017	.025
	Female	Male	-.004	.010	.724	-.025	.017
Stiffness	Male	Female	-.005	.007	.443	-.019	.008
	Female	Male	.005	.007	.443	-.008	.019

Appendix N: Processed FRP data

Table 60: FRP parameters processed data

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
1	Female	Pre-Fatigue	1	Right	6.31	84.23%	96.41%	130	23	153
1	Female	Pre-Fatigue	1	Left	6.40	81.41%	97.12%	150	16	166
1	Female	Pre-Fatigue	2	Right	5.55	77.41%	98.55%	147	21	168
1	Female	Pre-Fatigue	2	Left	5.47	77.41%	98.61%	147	20	167
1	Female	Pre-Fatigue	3	Right	5.92	78.34%	98.42%	140	22	162
1	Female	Pre-Fatigue	3	Left	5.91	77.37%	95.98%	147	18	165
1	Female	Post-Fatigue	1	Right	3.98	65.97%	89.53%	239	42	281
1	Female	Post-Fatigue	1	Left	4.12	65.97%	90.10%	239	40	279
1	Female	Post-Fatigue	2	Right	3.62	74.16%	93.81%	240	42	282
1	Female	Post-Fatigue	2	Left	3.66	73.60%	93.56%	250	43	293
1	Female	Post-Fatigue	3	Right	3.78	63.98%	93.88%	213	42	255
1	Female	Post-Fatigue	3	Left	3.57	63.68%	93.04%	215	47	262
1	Female	Recv 15	1	Right	6.44	77.83%	95.65%	140	28	175
1	Female	Recv 15	1	Left	6.47	75.92%	96.11%	146	24	178
1	Female	Recv 15	2	Right	4.77	78.40%	96.35%	146	29	176
1	Female	Recv 15	2	Left	5.05	75.64%	96.03%	156	27	189
1	Female	Recv 15	3	Right	6.74	75.40%	96.19%	144	21	165
1	Female	Recv 15	3	Left	6.62	75.40%	96.76%	144	18	162
1	Female	Recv 30	1	Right	6.11	77.30%	96.30%	139	24	163
1	Female	Recv 30	1	Left	5.99	76.47%	96.81%	142	21	163
1	Female	Recv 30	2	Right	6.22	78.99%	96.40%	145	22	167
1	Female	Recv 30	2	Left	5.72	79.45%	95.86%	142	24	166
1	Female	Recv 30	3	Right	6.07	81.23%	96.40%	145	24	172
1	Female	Recv 30	3	Left	5.92	80.14%	96.93%	155	22	180
1	Female	Recv 45	1	Right	6.00	79.25%	96.75%	147	23	170
1	Female	Recv 45	1	Left	6.05	81.12%	96.99%	139	22	161
1	Female	Recv 45	2	Right	5.81	77.73%	97.37%	148	19	167
1	Female	Recv 45	2	Left	6.01	78.32%	97.04%	145	22	167
1	Female	Recv 45	3	Right	6.09	79.25%	98.24%	144	19	163
1	Female	Recv 45	3	Left	6.13	79.98%	98.38%	140	18	158
1	Female	Recv 60	1	Right	6.02	84.41%	96.62%	135	19	154
1	Female	Recv 60	1	Left	6.70	80.59%	97.34%	146	14	160
1	Female	Recv 60	2	Right	5.47	77.59%	98.76%	162	23	185
1	Female	Recv 60	2	Left	5.66	77.59%	98.83%	149	19	168
1	Female	Recv 60	3	Right	6.23	78.51%	98.64%	131	22	153
1	Female	Recv 60	3	Left	6.01	77.54%	96.19%	137	22	159
2	Male	Pre-Fatigue	1	Right	4.79	76.36%	98.24%	97	27	124
2	Male	Pre-Fatigue	1	Left	4.86	76.18%	98.73%	98	21	119

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
2	Male	Pre-Fatigue	2	Right	4.71	75.41%	96.86%	112	11	123
2	Male	Pre-Fatigue	2	Left	4.67	73.52%	96.41%	118	15	133
2	Male	Pre-Fatigue	3	Right	5.13	82.36%	97.98%	102	11	113
2	Male	Pre-Fatigue	3	Left	4.86	80.25%	97.31%	108	17	125
2	Male	Post-Fatigue	1	Right	3.48	71.69%	95.92%	133	30	163
2	Male	Post-Fatigue	1	Left	2.69	69.54%	95.92%	147	30	177
2	Male	Post-Fatigue	2	Right	2.85	71.58%	91.60%	133	52	185
2	Male	Post-Fatigue	2	Left	2.83	71.90%	92.21%	131	44	175
2	Male	Post-Fatigue	3	Right	3.35	69.46%	88.75%	164	53	217
2	Male	Post-Fatigue	3	Left	2.58	67.26%	89.07%	175	51	226
2	Male	Recv 15	1	Right	4.66	76.44%	98.16%	120	23	143
2	Male	Recv 15	1	Left	4.72	76.44%	98.16%	120	23	143
2	Male	Recv 15	2	Right	5.22	75.99%	94.18%	109	14	123
2	Male	Recv 15	2	Left	4.54	76.68%	94.18%	105	14	119
2	Male	Recv 15	3	Right	5.10	77.75%	98.52%	110	13	123
2	Male	Recv 15	3	Left	4.36	77.11%	97.50%	112	23	135
2	Male	Recv 30	1	Right	4.63	79.59%	96.57%	111	21	132
2	Male	Recv 30	1	Left	5.03	79.59%	96.69%	111	20	131
2	Male	Recv 30	2	Right	5.28	76.91%	98.85%	111	18	129
2	Male	Recv 30	2	Left	4.53	77.51%	99.05%	109	15	124
2	Male	Recv 30	3	Right	4.73	75.76%	95.27%	100	17	117
2	Male	Recv 30	3	Left	4.84	75.59%	95.10%	101	18	119
2	Male	Recv 45	1	Right	4.84	72.28%	98.17%	107	20	127
2	Male	Recv 45	1	Left	5.01	74.91%	98.28%	99	19	118
2	Male	Recv 45	2	Right	5.09	79.20%	96.11%	106	19	125
2	Male	Recv 45	2	Left	4.63	78.65%	96.50%	108	15	123
2	Male	Recv 45	3	Right	4.80	78.98%	98.16%	110	14	124
2	Male	Recv 45	3	Left	4.67	80.04%	97.97%	106	15	121
2	Male	Recv 60	1	Right	4.67	80.04%	98.24%	95	17	112
2	Male	Recv 60	1	Left	4.92	77.20%	97.83%	100	23	123
2	Male	Recv 60	2	Right	5.42	77.77%	96.78%	108	22	130
2	Male	Recv 60	2	Left	4.65	76.11%	97.61%	116	16	132
2	Male	Recv 60	3	Right	4.71	76.65%	97.78%	105	12	117
2	Male	Recv 60	3	Left	4.72	76.65%	97.31%	107	11	118
3	Female	Pre-Fatigue	1	Right	4.99	85.63%	94.40%	105	17	122
3	Female	Pre-Fatigue	1	Left	4.78	85.44%	95.39%	106	14	120
3	Female	Pre-Fatigue	2	Right	4.84	82.87%	93.61%	109	21	130
3	Female	Pre-Fatigue	2	Left	4.71	81.44%	93.03%	117	23	140
3	Female	Pre-Fatigue	3	Right	6.35	82.38%	98.49%	109	20	129
3	Female	Pre-Fatigue	3	Left	6.02	81.74%	98.30%	112	22	134
3	Female	Post-Fatigue	1	Right	3.14	66.74%	87.37%	150	33	183

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
3	Female	Post-Fatigue	1	Left	2.89	67.24%	86.79%	148	35	183
3	Female	Post-Fatigue	2	Right	2.31	75.62%	92.68%	170	25	195
3	Female	Post-Fatigue	2	Left	2.00	72.87%	91.29%	190	32	222
3	Female	Post-Fatigue	3	Right	2.47	61.40%	93.32%	232	36	268
3	Female	Post-Fatigue	3	Left	2.23	60.85%	91.14%	235	44	279
3	Female	Recv 15	1	Right	5.06	85.26%	94.04%	104	18	122
3	Female	Recv 15	1	Left	5.29	85.26%	98.71%	104	18	122
3	Female	Recv 15	2	Right	5.00	74.54%	94.59%	110	21	131
3	Female	Recv 15	2	Left	4.99	74.36%	94.59%	112	21	133
3	Female	Recv 15	3	Right	5.18	74.52%	96.77%	101	19	120
3	Female	Recv 15	3	Left	5.35	73.64%	95.94%	104	23	127
3	Female	Recv 30	1	Right	5.21	77.12%	95.58%	104	21	125
3	Female	Recv 30	1	Left	5.46	76.59%	95.77%	107	20	127
3	Female	Recv 30	2	Right	5.74	78.66%	95.96%	101	19	120
3	Female	Recv 30	2	Left	4.27	77.52%	95.44%	105	22	127
3	Female	Recv 30	3	Right	5.81	79.77%	95.83%	110	18	128
3	Female	Recv 30	3	Left	4.39	80.25%	95.96%	108	17	125
3	Female	Recv 45	1	Right	5.44	83.36%	95.06%	114	21	135
3	Female	Recv 45	1	Left	5.28	82.94%	94.87%	116	22	138
3	Female	Recv 45	2	Right	5.14	84.12%	94.58%	107	21	128
3	Female	Recv 45	2	Left	5.24	83.87%	95.30%	109	18	127
3	Female	Recv 45	3	Right	5.44	81.47%	97.79%	112	16	128
3	Female	Recv 45	3	Left	5.24	83.10%	97.27%	105	19	124
3	Female	Recv 60	1	Right	5.10	85.63%	94.40%	111	17	128
3	Female	Recv 60	1	Left	5.43	85.44%	95.39%	110	21	131
3	Female	Recv 60	2	Right	5.41	82.78%	93.61%	106	22	128
3	Female	Recv 60	2	Left	5.05	81.44%	93.03%	108	18	126
3	Female	Recv 60	3	Right	5.56	82.38%	98.49%	113	21	134
3	Female	Recv 60	3	Left	5.24	81.74%	98.30%	112	17	129
4	Male	Pre-Fatigue	1	Right	5.62	80.96%	96.85%	89	23	112
4	Male	Pre-Fatigue	1	Left	4.96	80.96%	97.19%	89	18	107
4	Male	Pre-Fatigue	2	Right	5.58	78.18%	97.87%	82	26	108
4	Male	Pre-Fatigue	2	Left	5.18	77.92%	97.97%	83	29	112
4	Male	Pre-Fatigue	3	Right	5.61	74.95%	95.89%	96	22	118
4	Male	Pre-Fatigue	3	Left	4.90	78.28%	95.74%	87	28	115
4	Male	Post-Fatigue	1	Right	3.99	69.71%	92.51%	160	37	197
4	Male	Post-Fatigue	1	Left	3.74	69.45%	92.83%	161	34	195
4	Male	Post-Fatigue	2	Right	3.73	71.18%	92.83%	155	42	197
4	Male	Post-Fatigue	2	Left	4.30	70.22%	93.15%	159	39	198
4	Male	Post-Fatigue	3	Right	4.27	58.35%	93.74%	119	36	155
4	Male	Post-Fatigue	3	Left	3.20	59.95%	93.05%	113	32	145

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
4	Male	Recv 15	1	Right	4.66	76.16%	95.81%	99	26	125
4	Male	Recv 15	1	Left	4.65	76.16%	96.13%	99	24	123
4	Male	Recv 15	2	Right	4.69	79.92%	96.82%	78	24	102
4	Male	Recv 15	2	Left	5.18	80.17%	96.82%	77	24	101
4	Male	Recv 15	3	Right	5.45	75.97%	95.41%	82	26	108
4	Male	Recv 15	3	Left	4.87	76.34%	95.41%	81	26	107
4	Male	Recv 30	1	Right	5.16	77.74%	95.84%	90	26	116
4	Male	Recv 30	1	Left	5.01	77.44%	96.48%	89	24	113
4	Male	Recv 30	2	Right	5.00	77.45%	96.98%	78	21	99
4	Male	Recv 30	2	Left	5.13	77.06%	95.86%	77	26	103
4	Male	Recv 30	3	Right	5.13	78.10%	96.40%	92	25	117
4	Male	Recv 30	3	Left	5.25	77.46%	96.09%	94	26	120
4	Male	Recv 45	1	Right	5.45	79.32%	97.70%	88	23	111
4	Male	Recv 45	1	Left	5.20	79.55%	97.05%	87	25	112
4	Male	Recv 45	2	Right	5.25	77.41%	96.66%	82	24	106
4	Male	Recv 45	2	Left	5.27	76.27%	96.66%	87	24	111
4	Male	Recv 45	3	Right	5.82	79.23%	96.98%	91	22	113
4	Male	Recv 45	3	Left	4.83	79.49%	96.77%	90	27	117
4	Male	Recv 60	1	Right	4.77	80.96%	96.85%	92	26	118
4	Male	Recv 60	1	Left	5.35	80.96%	97.19%	86	22	108
4	Male	Recv 60	2	Right	5.58	78.18%	97.87%	85	22	107
4	Male	Recv 60	2	Left	5.38	77.92%	97.97%	91	23	114
4	Male	Recv 60	3	Right	5.67	74.95%	95.89%	92	27	119
4	Male	Recv 60	3	Left	5.14	78.28%	95.74%	79	24	103
5	Female	Pre-Fatigue	1	Right	3.63	76.93%	99.00%	77	14	91
5	Female	Pre-Fatigue	1	Left	3.99	77.20%	99.00%	76	14	90
5	Female	Pre-Fatigue	2	Right	3.60	79.14%	96.97%	82	21	103
5	Female	Pre-Fatigue	2	Left	4.15	81.86%	96.26%	72	27	99
5	Female	Pre-Fatigue	3	Right	4.52	75.79%	98.48%	78	17	95
5	Female	Pre-Fatigue	3	Left	3.59	74.65%	98.79%	85	14	99
5	Female	Post-Fatigue	1	Right	2.64	74.39%	94.29%	161	44	205
5	Female	Post-Fatigue	1	Left	2.81	72.89%	94.79%	167	42	209
5	Female	Post-Fatigue	2	Right	2.48	73.08%	90.12%	182	46	228
5	Female	Post-Fatigue	2	Left	2.56	72.85%	89.86%	186	47	233
5	Female	Post-Fatigue	3	Right	2.71	72.06%	95.93%	168	41	209
5	Female	Post-Fatigue	3	Left	2.92	72.06%	95.94%	168	47	215
5	Female	Recv 15	1	Right	3.79	76.10%	96.04%	99	22	121
5	Female	Recv 15	1	Left	3.79	75.48%	96.04%	101	22	123
5	Female	Recv 15	2	Right	4.05	77.91%	97.44%	95	21	116
5	Female	Recv 15	2	Left	3.91	78.24%	97.38%	102	22	124
5	Female	Recv 15	3	Right	3.73	77.57%	96.11%	95	16	111

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
5	Female	Recv 15	3	Left	3.70	76.48%	96.44%	100	24	124
5	Female	Recv 30	1	Right	3.78	77.04%	97.45%	79	20	99
5	Female	Recv 30	1	Left	3.88	76.77%	97.45%	80	20	100
5	Female	Recv 30	2	Right	3.95	77.15%	98.07%	89	20	109
5	Female	Recv 30	2	Left	3.85	78.34%	97.83%	79	23	102
5	Female	Recv 30	3	Right	4.04	77.98%	96.96%	90	21	111
5	Female	Recv 30	3	Left	3.97	78.35%	96.65%	88	19	107
5	Female	Recv 45	1	Right	3.82	75.12%	98.66%	80	18	98
5	Female	Recv 45	1	Left	3.67	76.09%	98.66%	73	18	91
5	Female	Recv 45	2	Right	3.95	78.22%	98.21%	77	23	100
5	Female	Recv 45	2	Left	3.85	78.51%	98.24%	75	22	97
5	Female	Recv 45	3	Right	4.13	79.15%	97.24%	79	14	93
5	Female	Recv 45	3	Left	4.07	79.95%	97.21%	88	13	101
5	Female	Recv 60	1	Right	3.88	76.93%	99.00%	76	19	95
5	Female	Recv 60	1	Left	4.10	77.20%	96.87%	81	14	95
5	Female	Recv 60	2	Right	4.33	79.14%	98.77%	82	16	98
5	Female	Recv 60	2	Left	3.77	81.86%	96.25%	77	13	90
5	Female	Recv 60	3	Right	3.90	75.79%	98.59%	82	21	103
5	Female	Recv 60	3	Left	3.53	74.65%	98.91%	73	22	95
6	Male	Pre-Fatigue	1	Right	3.56	80.43%	97.99%	76	13	89
6	Male	Pre-Fatigue	1	Left	3.34	80.01%	96.50%	77	24	101
6	Male	Pre-Fatigue	2	Right	3.45	81.25%	96.00%	91	21	112
6	Male	Pre-Fatigue	2	Left	3.64	81.01%	94.01%	92	29	121
6	Male	Pre-Fatigue	3	Right	3.03	78.63%	96.13%	78	25	103
6	Male	Pre-Fatigue	3	Left	3.03	77.77%	96.06%	81	29	110
6	Male	Post-Fatigue	1	Right	2.55	76.94%	91.11%	158	51	209
6	Male	Post-Fatigue	1	Left	2.89	75.75%	92.00%	164	46	210
6	Male	Post-Fatigue	2	Right	3.16	69.94%	87.46%	194	56	250
6	Male	Post-Fatigue	2	Left	2.67	71.69%	89.53%	184	43	227
6	Male	Post-Fatigue	3	Right	3.14	72.68%	89.70%	148	31	179
6	Male	Post-Fatigue	3	Left	2.85	74.83%	84.80%	140	47	187
6	Male	Recv 15	1	Right	3.09	79.54%	95.03%	88	27	115
6	Male	Recv 15	1	Left	3.34	78.82%	95.12%	83	25	108
6	Male	Recv 15	2	Right	3.47	78.24%	97.33%	95	22	117
6	Male	Recv 15	2	Left	3.43	79.24%	97.21%	94	23	117
6	Male	Recv 15	3	Right	3.46	77.48%	95.48%	94	25	119
6	Male	Recv 15	3	Left	3.11	78.26%	95.79%	92	24	116
6	Male	Recv 30	1	Right	3.35	78.29%	96.36%	82	22	104
6	Male	Recv 30	1	Left	3.36	78.75%	95.75%	89	24	113
6	Male	Recv 30	2	Right	3.27	79.04%	95.84%	88	24	112
6	Male	Recv 30	2	Left	3.29	78.71%	95.46%	89	25	114

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
6	Male	Recv 30	3	Right	3.35	79.79%	96.79%	84	24	108
6	Male	Recv 30	3	Left	3.42	78.91%	96.93%	89	22	111
6	Male	Recv 45	1	Right	3.62	79.30%	96.00%	87	24	111
6	Male	Recv 45	1	Left	3.24	79.72%	96.51%	85	22	107
6	Male	Recv 45	2	Right	3.21	80.50%	96.27%	79	23	102
6	Male	Recv 45	2	Left	3.23	79.44%	97.19%	84	20	104
6	Male	Recv 45	3	Right	3.17	80.26%	95.15%	80	26	106
6	Male	Recv 45	3	Left	3.60	79.94%	95.12%	79	25	104
6	Male	Recv 60	1	Right	3.68	80.01%	95.06%	83	23	106
6	Male	Recv 60	1	Left	3.59	80.67%	96.58%	85	19	104
6	Male	Recv 60	2	Right	3.12	81.25%	94.06%	79	21	100
6	Male	Recv 60	2	Left	3.49	78.63%	97.99%	76	24	100
6	Male	Recv 60	3	Right	3.11	78.65%	97.00%	88	25	113
6	Male	Recv 60	3	Left	3.06	81.34%	96.00%	83	27	110
7	Female	Pre-Fatigue	1	Right	5.01	82.67%	95.37%	110	22	132
7	Female	Pre-Fatigue	1	Left	4.63	83.95%	95.00%	99	24	123
7	Female	Pre-Fatigue	2	Right	4.59	76.92%	97.20%	70	12	82
7	Female	Pre-Fatigue	2	Left	3.94	80.16%	97.78%	62	8	70
7	Female	Pre-Fatigue	3	Right	5.33	71.55%	95.91%	94	28	122
7	Female	Pre-Fatigue	3	Left	5.28	73.58%	96.54%	87	23	110
7	Female	Post-Fatigue	1	Right	3.77	63.10%	87.03%	112	53	165
7	Female	Post-Fatigue	1	Left	3.67	63.10%	86.62%	112	56	168
7	Female	Post-Fatigue	2	Right	3.31	56.66%	83.07%	127	45	172
7	Female	Post-Fatigue	2	Left	3.40	59.31%	82.09%	117	49	166
7	Female	Post-Fatigue	3	Right	3.67	68.73%	90.74%	160	42	202
7	Female	Post-Fatigue	3	Left	3.71	76.50%	89.32%	134	50	184
7	Female	Recv 15	1	Right	4.90	76.13%	95.84%	75	20	95
7	Female	Recv 15	1	Left	4.48	77.58%	95.84%	71	20	91
7	Female	Recv 15	2	Right	4.93	75.64%	95.10%	108	23	131
7	Female	Recv 15	2	Left	4.23	78.10%	96.02%	98	20	118
7	Female	Recv 15	3	Right	5.08	73.93%	95.68%	85	22	107
7	Female	Recv 15	3	Left	5.06	74.46%	94.79%	83	21	104
7	Female	Recv 30	1	Right	4.54	76.08%	97.09%	77	20	97
7	Female	Recv 30	1	Left	5.04	75.47%	96.81%	80	21	101
7	Female	Recv 30	2	Right	5.05	77.22%	97.42%	86	22	108
7	Female	Recv 30	2	Left	5.00	78.96%	97.42%	83	22	105
7	Female	Recv 30	3	Right	5.21	77.46%	94.10%	98	20	118
7	Female	Recv 30	3	Left	4.12	77.69%	94.87%	97	19	116
7	Female	Recv 45	1	Right	5.27	76.40%	95.20%	86	19	105
7	Female	Recv 45	1	Left	5.23	77.29%	94.42%	84	21	105
7	Female	Recv 45	2	Right	4.36	78.15%	95.00%	85	21	106

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
7	Female	Recv 45	2	Left	5.19	79.25%	95.95%	82	17	99
7	Female	Recv 45	3	Right	4.10	79.71%	98.19%	90	20	110
7	Female	Recv 45	3	Left	4.67	78.24%	98.18%	93	21	114
7	Female	Recv 60	1	Right	5.01	82.67%	95.37%	103	19	122
7	Female	Recv 60	1	Left	4.77	83.46%	95.46%	100	22	122
7	Female	Recv 60	2	Right	4.35	71.80%	95.24%	82	21	103
7	Female	Recv 60	2	Left	5.34	73.84%	96.87%	84	19	103
7	Female	Recv 60	3	Right	4.71	76.92%	97.20%	77	21	98
7	Female	Recv 60	3	Left	4.65	80.16%	97.69%	76	16	92
8	Male	Pre-Fatigue	1	Right	3.60	83.69%	95.24%	104	22	126
8	Male	Pre-Fatigue	1	Left	4.02	84.98%	97.27%	99	15	114
8	Male	Pre-Fatigue	2	Right	4.39	75.47%	94.77%	72	28	100
8	Male	Pre-Fatigue	2	Left	3.60	75.84%	95.65%	71	22	93
8	Male	Pre-Fatigue	3	Right	3.91	79.57%	96.43%	97	28	125
8	Male	Pre-Fatigue	3	Left	4.95	80.21%	97.88%	94	21	115
8	Male	Post-Fatigue	1	Right	3.23	68.60%	89.86%	169	42	211
8	Male	Post-Fatigue	1	Left	3.63	69.19%	92.79%	166	32	198
8	Male	Post-Fatigue	2	Right	3.01	61.27%	92.80%	122	56	178
8	Male	Post-Fatigue	2	Left	2.83	59.86%	93.67%	129	50	179
8	Male	Post-Fatigue	3	Right	3.09	67.70%	88.01%	118	73	191
8	Male	Post-Fatigue	3	Left	3.59	63.03%	89.08%	136	68	204
8	Male	Recv 15	1	Right	4.12	78.43%	96.78%	88	19	107
8	Male	Recv 15	1	Left	3.96	79.94%	96.78%	90	19	109
8	Male	Recv 15	2	Right	3.74	77.23%	93.24%	91	26	117
8	Male	Recv 15	2	Left	4.57	77.99%	94.15%	92	23	115
8	Male	Recv 15	3	Right	3.98	79.47%	94.48%	98	27	125
8	Male	Recv 15	3	Left	3.65	81.15%	94.70%	100	26	126
8	Male	Recv 30	1	Right	3.58	79.48%	98.18%	81	24	105
8	Male	Recv 30	1	Left	4.71	78.54%	98.18%	86	24	110
8	Male	Recv 30	2	Right	3.47	82.36%	94.85%	98	23	121
8	Male	Recv 30	2	Left	4.43	81.61%	94.47%	100	25	125
8	Male	Recv 30	3	Right	3.72	77.67%	95.68%	95	20	115
8	Male	Recv 30	3	Left	4.32	79.03%	95.42%	89	21	110
8	Male	Recv 45	1	Right	4.24	76.85%	96.95%	100	22	122
8	Male	Recv 45	1	Left	4.11	76.36%	97.34%	102	18	120
8	Male	Recv 45	2	Right	3.10	81.89%	96.32%	80	24	104
8	Male	Recv 45	2	Left	4.55	80.27%	95.62%	85	28	113
8	Male	Recv 45	3	Right	3.59	81.03%	95.76%	84	20	104
8	Male	Recv 45	3	Left	4.93	81.82%	95.67%	82	21	103
8	Male	Recv 60	1	Right	3.80	80.21%	97.88%	90	19	109
8	Male	Recv 60	1	Left	3.68	78.77%	95.46%	101	23	124

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
8	Male	Recv 60	2	Right	4.17	78.77%	96.77%	79	24	103
8	Male	Recv 60	2	Left	4.36	79.03%	95.88%	84	21	105
8	Male	Recv 60	3	Right	4.21	79.77%	93.67%	91	23	114
8	Male	Recv 60	3	Left	4.30	82.41%	98.12%	91	23	114
9	Female	Pre-Fatigue	1	Right	6.00	75.43%	98.75%	69	15	84
9	Female	Pre-Fatigue	1	Left	6.10	75.43%	98.75%	69	15	84
9	Female	Pre-Fatigue	2	Right	5.53	76.71%	97.96%	89	18	107
9	Female	Pre-Fatigue	2	Left	4.87	78.25%	97.96%	85	19	104
9	Female	Pre-Fatigue	3	Right	5.72	80.00%	98.76%	96	22	118
9	Female	Pre-Fatigue	3	Left	5.25	78.31%	97.88%	101	23	124
9	Female	Post-Fatigue	1	Right	3.13	55.22%	97.20%	117	18	135
9	Female	Post-Fatigue	1	Left	3.67	55.22%	96.41%	117	23	140
9	Female	Post-Fatigue	2	Right	3.21	57.47%	98.71%	114	38	152
9	Female	Post-Fatigue	2	Left	2.73	58.73%	98.86%	110	34	144
9	Female	Post-Fatigue	3	Right	2.79	53.53%	96.67%	146	30	176
9	Female	Post-Fatigue	3	Left	2.40	59.11%	96.67%	126	30	156
9	Female	Recv 15	1	Right	5.15	65.59%	97.86%	82	23	105
9	Female	Recv 15	1	Left	4.94	66.74%	98.53%	77	18	95
9	Female	Recv 15	2	Right	5.90	77.57%	97.54%	90	21	111
9	Female	Recv 15	2	Left	4.93	76.86%	98.36%	92	24	116
9	Female	Recv 15	3	Right	6.58	74.43%	97.35%	87	21	108
9	Female	Recv 15	3	Left	5.81	74.07%	98.31%	88	22	110
9	Female	Recv 30	1	Right	6.69	74.72%	98.42%	89	19	108
9	Female	Recv 30	1	Left	4.64	74.29%	98.26%	91	20	111
9	Female	Recv 30	2	Right	5.80	75.16%	98.16%	81	17	98
9	Female	Recv 30	2	Left	5.07	75.75%	98.16%	79	17	96
9	Female	Recv 30	3	Right	6.69	74.75%	97.81%	87	21	108
9	Female	Recv 30	3	Left	4.64	75.05%	97.46%	86	23	109
9	Female	Recv 45	1	Right	6.23	77.39%	98.33%	78	12	90
9	Female	Recv 45	1	Left	4.91	75.69%	97.91%	74	17	91
9	Female	Recv 45	2	Right	5.45	81.00%	98.22%	89	18	107
9	Female	Recv 45	2	Left	5.40	80.46%	98.68%	92	15	107
9	Female	Recv 45	3	Right	6.94	74.88%	98.55%	89	26	115
9	Female	Recv 45	3	Left	4.51	75.39%	98.61%	87	25	112
9	Female	Recv 60	1	Right	5.56	79.04%	98.00%	86	20	106
9	Female	Recv 60	1	Left	5.65	76.89%	98.18%	80	19	99
9	Female	Recv 60	2	Right	5.00	75.43%	98.75%	93	17	110
9	Female	Recv 60	2	Left	5.88	77.67%	98.75%	81	16	97
9	Female	Recv 60	3	Right	5.68	76.71%	97.96%	79	20	99
9	Female	Recv 60	3	Left	5.79	80.25%	98.66%	88	19	107
10	Male	Pre-Fatigue	1	Right	6.76	83.69%	97.72%	96	8	104

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
10	Male	Pre-Fatigue	1	Left	5.21	83.69%	97.72%	96	8	104
10	Male	Pre-Fatigue	2	Right	5.00	76.33%	99.44%	80	13	93
10	Male	Pre-Fatigue	2	Left	6.59	75.66%	99.44%	83	13	96
10	Male	Pre-Fatigue	3	Right	6.16	81.39%	96.40%	89	12	101
10	Male	Pre-Fatigue	3	Left	6.70	80.79%	96.40%	92	12	104
10	Male	Post-Fatigue	1	Right	3.80	70.10%	94.25%	173	28	201
10	Male	Post-Fatigue	1	Left	4.18	69.49%	94.25%	181	28	209
10	Male	Post-Fatigue	2	Right	3.74	68.94%	92.76%	179	31	210
10	Male	Post-Fatigue	2	Left	3.74	69.10%	92.09%	178	24	202
10	Male	Post-Fatigue	3	Right	3.63	67.87%	94.06%	180	34	214
10	Male	Post-Fatigue	3	Left	4.67	68.93%	94.84%	174	35	209
10	Male	Recv 15	1	Right	5.56	77.22%	97.75%	112	12	124
10	Male	Recv 15	1	Left	6.24	76.51%	97.02%	118	15	133
10	Male	Recv 15	2	Right	6.28	79.22%	95.92%	121	16	137
10	Male	Recv 15	2	Left	5.89	78.89%	96.81%	124	11	135
10	Male	Recv 15	3	Right	5.67	79.49%	96.43%	104	12	116
10	Male	Recv 15	3	Left	6.57	79.29%	96.89%	95	13	108
10	Male	Recv 30	1	Right	6.00	81.31%	97.65%	96	12	108
10	Male	Recv 30	1	Left	6.27	81.17%	97.62%	97	13	110
10	Male	Recv 30	2	Right	6.29	79.99%	96.92%	105	11	116
10	Male	Recv 30	2	Left	5.81	80.21%	97.06%	104	10	114
10	Male	Recv 30	3	Right	5.86	79.12%	97.43%	102	12	114
10	Male	Recv 30	3	Left	6.18	79.12%	97.32%	102	11	113
10	Male	Recv 45	1	Right	6.77	80.88%	97.85%	94	13	107
10	Male	Recv 45	1	Left	5.86	80.59%	97.97%	95	12	107
10	Male	Recv 45	2	Right	5.81	81.37%	97.95%	96	13	109
10	Male	Recv 45	2	Left	6.17	81.97%	98.01%	91	12	103
10	Male	Recv 45	3	Right	5.90	78.42%	97.72%	80	8	88
10	Male	Recv 45	3	Left	5.90	78.42%	97.62%	80	9	89
10	Male	Recv 60	1	Right	6.12	81.41%	95.24%	95	12	107
10	Male	Recv 60	1	Left	5.91	76.80%	99.67%	94	13	107
10	Male	Recv 60	2	Right	5.42	83.69%	97.72%	82	9	91
10	Male	Recv 60	2	Left	6.82	82.85%	96.74%	79	8	87
10	Male	Recv 60	3	Right	6.00	77.99%	99.44%	88	11	99
10	Male	Recv 60	3	Left	6.15	78.71%	99.44%	96	13	109
11	Female	Pre-Fatigue	1	Right	5.32	80.85%	96.76%	89	24	113
11	Female	Pre-Fatigue	1	Left	5.25	79.80%	96.64%	99	20	119
11	Female	Pre-Fatigue	2	Right	4.15	78.54%	92.43%	92	17	109
11	Female	Pre-Fatigue	2	Left	4.44	77.36%	91.86%	98	19	117
11	Female	Pre-Fatigue	3	Right	4.37	79.03%	93.31%	108	24	132
11	Female	Pre-Fatigue	3	Left	4.18	79.55%	93.31%	106	24	130

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
11	Female	Post-Fatigue	1	Right	3.79	66.73%	98.48%	223	29	252
11	Female	Post-Fatigue	1	Left	3.59	66.73%	98.66%	223	27	250
11	Female	Post-Fatigue	2	Right	3.68	60.83%	97.85%	186	21	207
11	Female	Post-Fatigue	2	Left	3.72	60.83%	97.85%	186	21	207
11	Female	Post-Fatigue	3	Right	4.11	69.69%	97.93%	206	42	248
11	Female	Post-Fatigue	3	Left	4.00	71.89%	97.93%	194	42	236
11	Female	Recv 15	1	Right	4.37	75.52%	95.11%	110	22	132
11	Female	Recv 15	1	Left	4.80	74.91%	94.56%	113	24	137
11	Female	Recv 15	2	Right	4.45	77.15%	95.28%	91	21	112
11	Female	Recv 15	2	Left	4.63	76.94%	95.95%	92	18	110
11	Female	Recv 15	3	Right	4.71	76.05%	92.98%	98	25	123
11	Female	Recv 15	3	Left	4.73	75.16%	93.57%	104	24	128
11	Female	Recv 30	1	Right	4.41	76.81%	94.89%	97	20	117
11	Female	Recv 30	1	Left	4.59	76.40%	93.97%	99	23	122
11	Female	Recv 30	2	Right	4.65	78.77%	94.71%	105	23	128
11	Female	Recv 30	2	Left	4.84	79.35%	95.42%	102	19	121
11	Female	Recv 30	3	Right	4.69	79.04%	94.72%	102	21	123
11	Female	Recv 30	3	Left	4.50	79.38%	94.20%	99	24	123
11	Female	Recv 45	1	Right	3.97	78.12%	94.50%	100	19	119
11	Female	Recv 45	1	Left	5.00	78.27%	94.16%	99	21	120
11	Female	Recv 45	2	Right	4.89	79.97%	95.48%	90	21	111
11	Female	Recv 45	2	Left	4.46	79.85%	95.48%	92	20	112
11	Female	Recv 45	3	Right	4.67	80.49%	91.79%	104	25	129
11	Female	Recv 45	3	Left	4.72	80.17%	92.68%	106	21	127
11	Female	Recv 60	1	Right	4.67	78.08%	92.19%	99	22	121
11	Female	Recv 60	1	Left	4.32	78.72%	92.95%	92	19	111
11	Female	Recv 60	2	Right	4.11	80.85%	96.76%	88	23	111
11	Female	Recv 60	2	Left	5.35	80.03%	95.78%	102	20	122
11	Female	Recv 60	3	Right	4.71	78.54%	94.73%	104	18	122
11	Female	Recv 60	3	Left	4.51	79.36%	91.86%	106	25	131
12	Male	Pre-Fatigue	1	Right	4.40	79.35%	97.95%	92	20	112
12	Male	Pre-Fatigue	1	Left	5.51	78.16%	97.99%	96	16	112
12	Male	Pre-Fatigue	2	Right	5.44	78.48%	96.93%	85	22	107
12	Male	Pre-Fatigue	2	Left	4.56	78.01%	97.13%	88	20	108
12	Male	Pre-Fatigue	3	Right	3.95	83.97%	97.23%	100	20	120
12	Male	Pre-Fatigue	3	Left	4.29	83.31%	97.22%	105	21	126
12	Male	Post-Fatigue	1	Right	2.68	64.17%	92.69%	147	37	184
12	Male	Post-Fatigue	1	Left	2.53	63.91%	92.87%	148	36	184
12	Male	Post-Fatigue	2	Right	2.53	66.13%	93.05%	160	36	196
12	Male	Post-Fatigue	2	Left	2.97	67.33%	92.71%	155	38	193
12	Male	Post-Fatigue	3	Right	2.62	72.86%	93.50%	135	39	174

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
12	Male	Post-Fatigue	3	Left	2.78	72.66%	93.35%	136	42	178
12	Male	Recv 15	1	Right	4.72	76.82%	97.23%	89	26	115
12	Male	Recv 15	1	Left	4.47	76.82%	97.04%	89	29	118
12	Male	Recv 15	2	Right	5.61	78.53%	96.09%	93	12	105
12	Male	Recv 15	2	Left	4.79	78.44%	96.90%	94	13	107
12	Male	Recv 15	3	Right	4.33	79.08%	97.54%	101	22	123
12	Male	Recv 15	3	Left	4.66	78.24%	97.54%	103	22	125
12	Male	Recv 30	1	Right	4.90	78.68%	97.34%	96	22	118
12	Male	Recv 30	1	Left	4.76	79.62%	97.60%	91	18	109
12	Male	Recv 30	2	Right	5.35	79.36%	97.47%	93	22	115
12	Male	Recv 30	2	Left	3.54	78.90%	97.67%	95	19	114
12	Male	Recv 30	3	Right	4.87	76.93%	97.91%	95	19	114
12	Male	Recv 30	3	Left	4.77	76.74%	97.38%	96	21	117
12	Male	Recv 45	1	Right	5.03	80.41%	97.94%	89	21	110
12	Male	Recv 45	1	Left	4.55	79.66%	97.58%	91	24	115
12	Male	Recv 45	2	Right	4.43	79.90%	97.72%	93	20	113
12	Male	Recv 45	2	Left	4.82	80.19%	97.75%	92	18	110
12	Male	Recv 45	3	Right	4.57	80.85%	96.69%	98	18	116
12	Male	Recv 45	3	Left	4.74	80.28%	96.69%	102	18	120
12	Male	Recv 60	1	Right	4.89	82.96%	96.06%	95	21	116
12	Male	Recv 60	1	Left	5.13	79.97%	97.16%	93	17	110
12	Male	Recv 60	2	Right	4.66	79.35%	97.95%	97	18	115
12	Male	Recv 60	2	Left	4.49	78.89%	96.96%	94	24	118
12	Male	Recv 60	3	Right	4.35	78.48%	98.93%	93	16	109
12	Male	Recv 60	3	Left	4.68	79.90%	97.73%	92	22	114
13	Female	Pre-Fatigue	1	Right	5.72	78.95%	95.36%	82	16	98
13	Female	Pre-Fatigue	1	Left	5.72	79.27%	95.68%	80	14	94
13	Female	Pre-Fatigue	3	Right	5.61	78.81%	93.76%	85	19	104
13	Female	Pre-Fatigue	3	Left	5.61	79.29%	94.50%	81	15	96
13	Female	Pre-Fatigue	4	Right	5.87	79.27%	96.20%	87	15	102
13	Female	Pre-Fatigue	4	Left	5.87	79.27%	95.31%	87	20	107
13	Female	Post-Fatigue	1	Right	3.80	67.78%	92.06%	152	30	182
13	Female	Post-Fatigue	1	Left	3.86	65.66%	86.52%	161	36	197
13	Female	Post-Fatigue	2	Right	3.85	67.39%	88.72%	151	43	194
13	Female	Post-Fatigue	2	Left	3.85	70.40%	88.72%	138	43	181
13	Female	Post-Fatigue	3	Right	3.22	65.43%	91.15%	139	36	175
13	Female	Post-Fatigue	3	Left	3.22	66.89%	92.77%	135	30	165
13	Female	Recv 15	1	Right	5.75	73.02%	93.45%	102	26	128
13	Female	Recv 15	1	Left	5.75	73.02%	95.33%	102	28	130
13	Female	Recv 15	2	Right	5.69	72.76%	94.09%	101	19	120
13	Female	Recv 15	2	Left	5.69	73.56%	94.25%	101	16	117

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
13	Female	Recv 15	3	Right	5.67	77.36%	95.24%	94	14	108
13	Female	Recv 15	3	Left	5.67	77.36%	95.24%	94	14	108
13	Female	Recv 30	1	Right	5.83	79.42%	94.97%	88	18	106
13	Female	Recv 30	1	Left	5.83	78.79%	94.78%	84	19	103
13	Female	Recv 30	2	Right	5.44	76.64%	95.12%	86	19	105
13	Female	Recv 30	2	Left	5.44	78.19%	95.12%	79	19	98
13	Female	Recv 30	3	Right	5.97	78.09%	95.49%	93	18	111
13	Female	Recv 30	3	Left	5.83	78.32%	94.96%	92	20	112
13	Female	Recv 45	1	Right	5.80	79.09%	94.75%	87	18	105
13	Female	Recv 45	1	Left	5.79	79.61%	94.59%	85	19	104
13	Female	Recv 45	2	Right	6.05	79.83%	93.84%	78	15	93
13	Female	Recv 45	2	Left	5.74	79.37%	94.19%	80	14	94
13	Female	Recv 45	3	Right	5.51	78.17%	96.62%	85	15	100
13	Female	Recv 45	3	Left	5.51	78.00%	96.37%	86	18	104
13	Female	Recv 60	1	Right	5.88	78.32%	95.04%	85	16	101
13	Female	Recv 60	1	Left	5.46	78.99%	93.98%	81	17	98
13	Female	Recv 60	2	Right	4.90	78.95%	95.36%	84	20	104
13	Female	Recv 60	2	Left	6.29	78.89%	94.39%	86	16	102
13	Female	Recv 60	3	Right	5.95	78.80%	96.76%	80	15	95
13	Female	Recv 60	3	Left	5.87	79.89%	94.80%	85	14	99
14	Male	Pre-Fatigue	1	Right	3.71	77.48%	98.83%	87	20	107
14	Male	Pre-Fatigue	1	Left	4.06	78.23%	98.59%	84	20	104
14	Male	Pre-Fatigue	2	Right	3.70	82.37%	98.25%	86	22	108
14	Male	Pre-Fatigue	2	Left	3.98	82.66%	98.61%	85	19	104
14	Male	Pre-Fatigue	3	Right	3.97	80.84%	98.90%	88	19	107
14	Male	Pre-Fatigue	3	Left	3.94	82.33%	99.19%	86	17	103
14	Male	Post-Fatigue	1	Right	3.15	61.01%	91.77%	125	46	171
14	Male	Post-Fatigue	1	Left	3.56	60.47%	90.63%	126	48	174
14	Male	Post-Fatigue	2	Right	3.45	64.27%	92.81%	141	41	182
14	Male	Post-Fatigue	2	Left	3.33	65.01%	92.63%	139	42	181
14	Male	Post-Fatigue	3	Right	2.81	58.00%	94.58%	130	44	174
14	Male	Post-Fatigue	3	Left	3.01	57.75%	94.36%	131	45	176
14	Male	Recv 15	1	Right	3.87	73.59%	97.52%	85	19	104
14	Male	Recv 15	1	Left	3.92	73.24%	97.52%	86	19	105
14	Male	Recv 15	2	Right	3.80	73.45%	94.98%	85	17	102
14	Male	Recv 15	2	Left	3.85	73.45%	94.10%	85	19	104
14	Male	Recv 15	3	Right	3.85	77.70%	98.26%	90	31	121
14	Male	Recv 15	3	Left	3.92	76.20%	98.26%	96	31	127
14	Male	Recv 30	1	Right	4.12	76.28%	97.95%	91	22	113
14	Male	Recv 30	1	Left	3.91	75.79%	98.07%	83	21	104
14	Male	Recv 30	2	Right	3.77	75.60%	97.16%	81	20	101

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
14	Male	Recv 30	2	Left	4.13	76.16%	96.94%	79	22	101
14	Male	Recv 30	3	Right	3.59	77.87%	97.39%	94	20	114
14	Male	Recv 30	3	Left	3.74	78.38%	96.97%	92	22	114
14	Male	Recv 45	1	Right	3.41	80.53%	98.39%	83	19	102
14	Male	Recv 45	1	Left	3.52	80.02%	98.55%	85	18	103
14	Male	Recv 45	2	Right	4.08	81.09%	98.89%	85	20	105
14	Male	Recv 45	2	Left	4.02	80.40%	98.67%	88	22	110
14	Male	Recv 45	3	Right	4.20	79.72%	98.95%	88	19	107
14	Male	Recv 45	3	Left	4.13	79.95%	98.77%	87	21	108
14	Male	Recv 60	1	Right	4.19	79.87%	97.71%	88	18	106
14	Male	Recv 60	1	Left	3.67	82.56%	98.98%	90	24	114
14	Male	Recv 60	2	Right	3.76	78.77%	98.83%	78	23	101
14	Male	Recv 60	2	Left	4.48	76.70%	98.83%	85	16	101
14	Male	Recv 60	3	Right	3.57	82.37%	98.25%	94	19	113
14	Male	Recv 60	3	Left	3.75	82.66%	99.81%	82	18	100
15	Female	Pre-Fatigue	1	Right	4.64	83.98%	95.36%	85	34	119
15	Female	Pre-Fatigue	1	Left	6.33	81.04%	96.45%	99	27	126
15	Female	Pre-Fatigue	2	Right	5.26	85.03%	98.93%	82	21	103
15	Female	Pre-Fatigue	2	Left	5.03	83.55%	98.93%	95	21	116
15	Female	Pre-Fatigue	3	Right	3.54	84.11%	97.03%	70	18	88
15	Female	Pre-Fatigue	3	Left	4.04	84.56%	96.80%	68	19	87
15	Female	Post-Fatigue	1	Right	2.21	62.05%	92.00%	143	43	186
15	Female	Post-Fatigue	1	Left	2.25	71.93%	89.30%	122	55	177
15	Female	Post-Fatigue	2	Right	2.21	73.12%	89.49%	127	74	201
15	Female	Post-Fatigue	2	Left	2.23	71.22%	93.16%	133	53	186
15	Female	Post-Fatigue	3	Right	3.50	74.52%	95.61%	150	38	188
15	Female	Post-Fatigue	3	Left	3.69	73.53%	94.96%	156	45	201
15	Female	Recv 15	1	Right	4.28	81.07%	97.08%	89	21	110
15	Female	Recv 15	1	Left	4.14	81.07%	97.17%	89	20	109
15	Female	Recv 15	2	Right	4.40	81.46%	94.62%	86	26	112
15	Female	Recv 15	2	Left	5.47	80.36%	95.17%	93	24	117
15	Female	Recv 15	3	Right	5.01	78.56%	97.49%	91	25	116
15	Female	Recv 15	3	Left	4.49	78.27%	97.19%	92	28	120
15	Female	Recv 30	1	Right	4.23	82.27%	97.89%	87	24	24
15	Female	Recv 30	1	Left	4.74	82.41%	98.40%	78	27	105
15	Female	Recv 30	2	Right	5.00	78.11%	96.87%	91	25	116
15	Female	Recv 30	2	Left	4.59	80.37%	97.48%	87	22	109
15	Female	Recv 30	3	Right	5.36	82.08%	95.92%	88	21	109
15	Female	Recv 30	3	Left	4.73	82.71%	95.73%	86	22	108
15	Female	Recv 45	1	Right	4.89	83.90%	97.35%	85	24	109
15	Female	Recv 45	1	Left	4.63	83.55%	97.17%	88	25	113

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
15	Female	Recv 45	2	Right	5.65	82.69%	97.17%	80	23	103
15	Female	Recv 45	2	Left	5.13	83.16%	97.53%	77	21	98
15	Female	Recv 45	3	Right	4.28	84.68%	97.17%	82	21	103
15	Female	Recv 45	3	Left	4.26	84.01%	97.17%	88	26	114
15	Female	Recv 60	1	Right	5.16	82.26%	94.89%	85	27	112
15	Female	Recv 60	1	Left	4.65	85.03%	98.93%	80	20	100
15	Female	Recv 60	2	Right	4.85	83.98%	95.47%	83	18	101
15	Female	Recv 60	2	Left	5.35	83.99%	96.23%	87	24	111
15	Female	Recv 60	3	Right	4.65	85.03%	98.93%	81	25	106
15	Female	Recv 60	3	Left	4.18	83.55%	98.93%	83	24	107
16	Male	Pre-Fatigue	1	Right	3.72	85.11%	97.97%	85	14	99
16	Male	Pre-Fatigue	1	Left	3.96	84.74%	97.09%	88	19	107
16	Male	Pre-Fatigue	2	Right	4.09	85.86%	98.38%	99	34	133
16	Male	Pre-Fatigue	2	Left	4.39	85.19%	98.66%	103	31	134
16	Male	Pre-Fatigue	3	Right	4.37	85.62%	97.15%	101	15	116
16	Male	Pre-Fatigue	3	Left	3.86	85.31%	96.88%	103	16	119
16	Male	Post-Fatigue	1	Right	2.92	71.27%	91.83%	160	32	192
16	Male	Post-Fatigue	1	Left	3.27	70.09%	89.46%	166	41	207
16	Male	Post-Fatigue	2	Right	2.67	71.12%	87.54%	179	52	231
16	Male	Post-Fatigue	2	Left	3.27	71.74%	88.80%	173	47	220
16	Male	Post-Fatigue	3	Right	2.62	67.90%	92.87%	195	38	233
16	Male	Post-Fatigue	3	Left	3.32	67.27%	91.37%	198	45	243
16	Male	Recv 15	1	Right	4.14	85.12%	97.64%	100	26	126
16	Male	Recv 15	1	Left	4.14	84.88%	97.64%	103	26	129
16	Male	Recv 15	2	Right	4.21	81.27%	96.61%	91	20	111
16	Male	Recv 15	2	Left	4.30	80.89%	98.06%	93	18	111
16	Male	Recv 15	3	Right	3.37	86.38%	96.99%	107	23	130
16	Male	Recv 15	3	Left	3.37	86.16%	96.99%	110	23	133
16	Male	Recv 30	1	Right	4.57	84.73%	96.85%	100	22	122
16	Male	Recv 30	1	Left	3.70	85.50%	97.23%	95	19	114
16	Male	Recv 30	2	Right	4.06	85.11%	97.69%	93	23	116
16	Male	Recv 30	2	Left	3.92	84.24%	97.75%	99	22	121
16	Male	Recv 30	3	Right	3.95	85.24%	98.57%	99	24	123
16	Male	Recv 30	3	Left	3.98	84.69%	98.68%	103	22	125
16	Male	Recv 45	1	Right	3.57	85.35%	97.46%	93	22	115
16	Male	Recv 45	1	Left	4.44	85.10%	97.70%	95	20	115
16	Male	Recv 45	2	Right	4.22	83.98%	97.99%	89	20	109
16	Male	Recv 45	2	Left	3.89	84.04%	97.90%	87	23	110
16	Male	Recv 45	3	Right	4.00	86.65%	97.33%	104	20	124
16	Male	Recv 45	3	Left	4.38	86.49%	96.88%	107	22	129
16	Male	Recv 60	1	Right	3.79	83.73%	95.01%	100	23	123

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
16	Male	Recv 60	1	Left	5.06	85.86%	98.38%	94	20	114
16	Male	Recv 60	2	Right	4.30	86.46%	98.08%	88	21	109
16	Male	Recv 60	2	Left	4.00	85.12%	98.86%	94	24	118
16	Male	Recv 60	3	Right	3.47	85.86%	98.38%	99	18	117
16	Male	Recv 60	3	Left	3.86	85.19%	98.38%	98	21	119
17	Female	Pre-Fatigue	1	Right	5.05	84.66%	99.25%	85	19	104
17	Female	Pre-Fatigue	1	Left	4.75	85.59%	98.81%	81	23	104
17	Female	Pre-Fatigue	2	Right	4.75	77.49%	99.15%	84	25	109
17	Female	Pre-Fatigue	2	Left	5.32	76.83%	99.45%	89	21	110
17	Female	Pre-Fatigue	3	Right	5.68	80.90%	99.59%	84	19	103
17	Female	Pre-Fatigue	3	Left	6.12	80.90%	99.62%	84	18	102
17	Female	Post-Fatigue	1	Right	4.20	68.26%	96.82%	142	27	169
17	Female	Post-Fatigue	1	Left	3.55	67.86%	67.86%	144	25	169
17	Female	Post-Fatigue	2	Right	3.68	66.67%	98.12%	137	29	166
17	Female	Post-Fatigue	2	Left	3.53	65.97%	98.12%	139	29	168
17	Female	Post-Fatigue	3	Right	3.93	72.07%	95.68%	140	30	170
17	Female	Post-Fatigue	3	Left	3.72	71.36%	96.39%	142	26	168
17	Female	Recv 15	1	Right	4.92	79.20%	96.74%	93	19	112
17	Female	Recv 15	1	Left	5.68	79.41%	96.97%	92	21	113
17	Female	Recv 15	2	Right	5.02	77.18%	97.56%	103	25	128
17	Female	Recv 15	2	Left	4.99	77.32%	97.92%	102	22	124
17	Female	Recv 15	3	Right	4.90	75.31%	98.79%	92	22	114
17	Female	Recv 15	3	Left	5.41	74.63%	98.79%	95	22	117
17	Female	Recv 30	1	Right	5.20	78.59%	97.80%	100	19	119
17	Female	Recv 30	1	Left	5.53	79.10%	97.66%	98	20	119
17	Female	Recv 30	2	Right	5.31	79.32%	98.02%	81	22	118
17	Female	Recv 30	2	Left	4.95	79.99%	98.35%	77	20	103
17	Female	Recv 30	3	Right	5.01	78.09%	98.17%	90	18	97
17	Female	Recv 30	3	Left	5.40	78.66%	97.18%	86	27	113
17	Female	Recv 45	1	Right	5.52	81.78%	98.97%	85	21	106
17	Female	Recv 45	1	Left	6.51	81.13%	98.85%	88	22	110
17	Female	Recv 45	2	Right	4.21	79.94%	99.22%	80	20	100
17	Female	Recv 45	2	Left	5.91	79.52%	99.07%	82	22	104
17	Female	Recv 45	3	Right	4.63	81.36%	99.94%	86	19	105
17	Female	Recv 45	3	Left	5.01	81.05%	99.86%	88	20	108
17	Female	Recv 60	1	Right	5.50	79.12%	99.39%	86	20	106
17	Female	Recv 60	1	Left	5.20	78.90%	99.15%	82	22	104
17	Female	Recv 60	2	Right	4.47	84.66%	99.36%	78	23	101
17	Female	Recv 60	2	Left	4.76	84.67%	99.51%	90	19	109
17	Female	Recv 60	3	Right	5.84	79.49%	99.15%	88	22	110
17	Female	Recv 60	3	Left	6.05	79.63%	99.15%	81	18	99

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
18	Male	Pre-Fatigue	1	Right	3.44	80.41%	94.68%	98	18	116
18	Male	Pre-Fatigue	1	Left	3.77	82.29%	94.40%	91	19	110
18	Male	Pre-Fatigue	2	Right	4.02	84.37%	96.88%	85	36	121
18	Male	Pre-Fatigue	2	Left	3.78	83.76%	98.22%	88	21	109
18	Male	Pre-Fatigue	3	Right	4.84	83.46%	92.83%	78	21	99
18	Male	Pre-Fatigue	3	Left	5.46	77.19%	93.15%	109	20	129
18	Male	Post-Fatigue	1	Right	2.63	67.62%	89.92%	120	42	162
18	Male	Post-Fatigue	1	Left	2.69	68.34%	89.92%	118	42	160
18	Male	Post-Fatigue	2	Right	2.83	67.83%	91.15%	148	37	185
18	Male	Post-Fatigue	2	Left	3.01	67.60%	89.10%	149	44	193
18	Male	Post-Fatigue	3	Right	2.94	70.15%	88.30%	200	50	250
18	Male	Post-Fatigue	3	Left	3.08	69.38%	87.83%	203	52	255
18	Male	Recv 15	1	Right	4.04	79.53%	95.28%	101	23	124
18	Male	Recv 15	1	Left	4.42	80.73%	94.95%	97	25	122
18	Male	Recv 15	2	Right	4.20	77.02%	94.44%	88	22	110
18	Male	Recv 15	2	Left	4.20	77.30%	94.31%	87	25	112
18	Male	Recv 15	3	Right	4.04	76.23%	94.31%	101	25	126
18	Male	Recv 15	3	Left	4.32	76.23%	95.18%	101	25	126
18	Male	Recv 30	1	Right	4.33	79.01%	93.50%	92	21	113
18	Male	Recv 30	1	Left	4.03	78.16%	93.50%	96	21	117
18	Male	Recv 30	2	Right	4.19	81.33%	95.30%	92	23	115
18	Male	Recv 30	2	Left	4.22	81.75%	95.43%	90	22	112
18	Male	Recv 30	3	Right	4.13	78.43%	95.82%	94	22	116
18	Male	Recv 30	3	Left	4.54	78.43%	95.22%	94	25	119
18	Male	Recv 45	1	Right	4.17	81.08%	94.34%	91	20	111
18	Male	Recv 45	1	Left	4.54	79.74%	94.07%	98	21	119
18	Male	Recv 45	2	Right	4.24	82.05%	96.15%	83	20	103
18	Male	Recv 45	2	Left	3.84	82.77%	95.99%	81	21	102
18	Male	Recv 45	3	Right	4.29	82.80%	95.74%	98	22	120
18	Male	Recv 45	3	Left	4.14	83.13%	94.29%	96	29	125
18	Male	Recv 60	1	Right	4.16	82.46%	91.72%	95	22	117
18	Male	Recv 60	1	Left	4.05	84.57%	97.11%	93	24	117
18	Male	Recv 60	2	Right	3.97	80.41%	94.68%	84	20	104
18	Male	Recv 60	2	Left	4.37	79.59%	93.72%	88	21	109
18	Male	Recv 60	3	Right	4.59	84.37%	96.88%	94	24	118
18	Male	Recv 60	3	Left	4.15	83.76%	98.22%	96	23	119
19	Female	Pre-Fatigue	1	Right	6.47	80.59%	94.73%	102	19	121
19	Female	Pre-Fatigue	1	Left	6.03	79.81%	95.82%	105	15	120
19	Female	Pre-Fatigue	2	Right	6.47	81.29%	97.85%	105	23	128
19	Female	Pre-Fatigue	2	Left	5.66	78.04%	97.49%	81	25	106
19	Female	Pre-Fatigue	3	Right	6.71	78.74%	97.51%	114	22	136

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
19	Female	Pre-Fatigue	3	Left	6.36	75.43%	97.69%	103	20	123
19	Female	Post-Fatigue	1	Right	4.67	62.72%	95.46%	217	22	239
19	Female	Post-Fatigue	1	Left	4.57	63.98%	94.00%	211	29	240
19	Female	Post-Fatigue	2	Right	4.41	71.34%	93.53%	159	30	189
19	Female	Post-Fatigue	2	Left	4.76	69.93%	93.96%	165	29	194
19	Female	Post-Fatigue	3	Right	4.43	59.43%	88.40%	206	49	255
19	Female	Post-Fatigue	3	Left	5.22	60.67%	87.90%	201	52	253
19	Female	Recv 15	1	Right	6.26	78.00%	96.86%	107	25	132
19	Female	Recv 15	1	Left	5.98	77.20%	96.67%	112	26	138
19	Female	Recv 15	2	Right	5.91	77.65%	96.58%	109	22	131
19	Female	Recv 15	2	Left	6.35	75.18%	96.21%	121	23	144
19	Female	Recv 15	3	Right	5.75	76.62%	95.47%	100	17	117
19	Female	Recv 15	3	Left	5.32	75.68%	96.04%	103	15	118
19	Female	Recv 30	1	Right	5.28	77.51%	96.28%	103	23	126
19	Female	Recv 30	1	Left	7.45	77.06%	96.56%	105	21	126
19	Female	Recv 30	2	Right	6.18	78.54%	96.60%	106	21	127
19	Female	Recv 30	2	Left	6.35	79.38%	97.15%	103	17	120
19	Female	Recv 30	3	Right	6.20	77.50%	96.13%	103	21	124
19	Female	Recv 30	3	Left	6.16	76.97%	95.83%	106	22	128
19	Female	Recv 45	1	Right	6.30	80.79%	97.24%	106	21	127
19	Female	Recv 45	1	Left	6.15	80.08%	97.50%	110	20	130
19	Female	Recv 45	2	Right	6.00	80.63%	96.37%	95	22	117
19	Female	Recv 45	2	Left	6.48	77.20%	95.96%	108	24	132
19	Female	Recv 45	3	Right	6.37	78.14%	96.57%	96	20	116
19	Female	Recv 45	3	Left	6.38	77.89%	97.04%	94	18	112
19	Female	Recv 60	1	Right	6.44	77.80%	96.34%	105	23	128
19	Female	Recv 60	1	Left	5.69	81.48%	98.08%	103	19	122
19	Female	Recv 60	2	Right	5.98	80.59%	96.73%	108	21	129
19	Female	Recv 60	2	Left	6.68	79.77%	95.77%	99	25	124
19	Female	Recv 60	3	Right	6.48	78.29%	97.85%	96	18	114
19	Female	Recv 60	3	Left	6.44	77.03%	97.49%	97	17	114
20	Male	Pre-Fatigue	1	Right	6.13	83.96%	95.81%	80	21	101
20	Male	Pre-Fatigue	1	Left	6.13	83.32%	96.79%	83	13	96
20	Male	Pre-Fatigue	2	Right	4.01	78.00%	95.73%	89	16	105
20	Male	Pre-Fatigue	2	Left	4.77	76.57%	95.58%	94	17	111
20	Male	Pre-Fatigue	3	Right	3.99	86.87%	96.19%	75	14	89
20	Male	Pre-Fatigue	3	Left	4.71	82.66%	96.51%	92	12	104
20	Male	Post-Fatigue	1	Right	3.37	74.47%	93.55%	154	21	175
20	Male	Post-Fatigue	1	Left	3.56	72.88%	93.88%	163	20	183
20	Male	Post-Fatigue	2	Right	3.57	74.41%	93.41%	131	25	156
20	Male	Post-Fatigue	2	Left	3.85	74.75%	93.41%	130	25	155

Subject	Gender	Status	Trial	Side	FRR	Onset	Offset	T1	T2	Expansion
20	Male	Post-Fatigue	3	Right	3.80	71.10%	93.14%	144	33	177
20	Male	Post-Fatigue	3	Left	3.97	70.24%	93.55%	147	31	178
20	Male	Recv 15	1	Right	5.05	81.31%	94.90%	94	19	113
20	Male	Recv 15	1	Left	4.83	81.49%	95.72%	93	14	107
20	Male	Recv 15	2	Right	5.23	80.25%	96.46%	100	14	114
20	Male	Recv 15	2	Left	5.11	80.25%	96.46%	100	14	114
20	Male	Recv 15	3	Right	4.77	76.78%	95.22%	89	17	106
20	Male	Recv 15	3	Left	4.91	76.42%	95.11%	91	19	110
20	Male	Recv 30	1	Right	5.13	80.16%	95.31%	94	16	110
20	Male	Recv 30	1	Left	4.85	81.28%	96.42%	89	11	100
20	Male	Recv 30	2	Right	5.13	79.65%	95.92%	93	16	109
20	Male	Recv 30	2	Left	4.43	79.90%	95.73%	92	17	109
20	Male	Recv 30	3	Right	5.16	79.21%	96.56%	82	17	99
20	Male	Recv 30	3	Left	5.22	80.09%	96.15%	78	20	98
20	Male	Recv 45	1	Right	4.80	81.47%	96.03%	89	19	108
20	Male	Recv 45	1	Left	5.03	81.17%	96.21%	90	18	108
20	Male	Recv 45	2	Right	4.85	82.13%	96.00%	81	16	97
20	Male	Recv 45	2	Left	5.06	81.94%	96.30%	82	13	95
20	Male	Recv 45	3	Right	5.00	82.29%	96.23%	87	14	101
20	Male	Recv 45	3	Left	4.92	82.70%	96.23%	85	14	99
20	Male	Recv 60	1	Right	5.09	85.83%	95.04%	88	17	105
20	Male	Recv 60	1	Left	5.15	78.18%	95.95%	86	16	102
20	Male	Recv 60	2	Right	4.68	84.96%	95.81%	89	15	104
20	Male	Recv 60	2	Left	4.95	83.11%	94.84%	96	18	114
20	Male	Recv 60	3	Right	4.80	80.00%	98.72%	78	13	91
20	Male	Recv 60	3	Left	5.04	79.57%	97.18%	76	14	90

Appendix O: Processed SP data

Table 61: SP temporal parameters and intrinsic stiffness data

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness*
1	Female	Pre-Fatigue	1	Right	66	289	152	1047.029
1	Female	Pre-Fatigue	1	Left	81	284	147	
1	Female	Pre-Fatigue	2	Right	56	216	80	1187.451
1	Female	Pre-Fatigue	2	Left	50	221	85	
1	Female	Pre-Fatigue	3	Right	61	210	69	1049.319
1	Female	Pre-Fatigue	3	Left	61	200	59	
1	Female	Post-Fatigue	1	Right	78	405	212	925.6998
1	Female	Post-Fatigue	1	Left	85	396	213	
1	Female	Post-Fatigue	2	Right	82	307	218	988.0748
1	Female	Post-Fatigue	2	Left	75	316	227	
1	Female	Post-Fatigue	3	Right	106	397	214	993.6665
1	Female	Post-Fatigue	3	Left	84	400	217	
1	Female	Recv 15	1	Right	72	282	131	1150.051
1	Female	Recv 15	1	Left	75	311	140	
1	Female	Recv 15	2	Right	74	254	105	1067.867
1	Female	Recv 15	2	Left	64	250	101	
1	Female	Recv 15	3	Right	57	258	100	1023.272
1	Female	Recv 15	3	Left	76	260	102	
1	Female	Recv 30	1	Right	73	260	112	1040.308
1	Female	Recv 30	1	Left	71	270	122	
1	Female	Recv 30	2	Right	55	248	98	1120.594
1	Female	Recv 30	2	Left	56	249	99	
1	Female	Recv 30	3	Right	62	251	97	1096.178
1	Female	Recv 30	3	Left	79	248	94	
1	Female	Recv 45	1	Right	66	291	153	1193.468
1	Female	Recv 45	1	Left	82	286	147	
1	Female	Recv 45	2	Right	56	217	80	1065.788
1	Female	Recv 45	2	Left	50	223	85	
1	Female	Recv 45	3	Right	61	211	69	1019.547
1	Female	Recv 45	3	Left	61	201	59	
1	Female	Recv 60	1	Right	66	288	151	1203.566
1	Female	Recv 60	1	Left	81	283	146	
1	Female	Recv 60	2	Right	56	215	79	979.4547
1	Female	Recv 60	2	Left	50	220	84	
1	Female	Recv 60	3	Right	60	209	68	1099.565

* Stiffness = intrinsic stiffness. There is no left or right side for stiffness and the data was tabulated under the right side for convenience only.

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
1	Female	Recv 60	3	Left	60	199	58	
2	Male	Pre-Fatigue	1	Right	93	235	108	855.6704
2	Male	Pre-Fatigue	1	Left	89	228	101	
2	Male	Pre-Fatigue	2	Right	82	234	108	939.9171
2	Male	Pre-Fatigue	2	Left	102	250	124	
2	Male	Pre-Fatigue	3	Right	98	221	81	962.6456
2	Male	Pre-Fatigue	3	Left	74	254	114	
2	Male	Post-Fatigue	1	Right	171	323	199	644.2204
2	Male	Post-Fatigue	1	Left	162	288	164	
2	Male	Post-Fatigue	2	Right	183	313	183	791.3065
2	Male	Post-Fatigue	2	Left	182	313	183	
2	Male	Post-Fatigue	3	Right	188	197	172	722.1882
2	Male	Post-Fatigue	3	Left	188	283	158	
2	Male	Recv 15	1	Right	90	246	106	821.3672
2	Male	Recv 15	1	Left	89	254	114	
2	Male	Recv 15	2	Right	85	235	110	973.2744
2	Male	Recv 15	2	Left	72	236	101	
2	Male	Recv 15	3	Right	112	239	114	876.9634
2	Male	Recv 15	3	Left	108	236	111	
2	Male	Recv 30	1	Right	75	247	103	847.3384
2	Male	Recv 30	1	Left	68	249	105	
2	Male	Recv 30	2	Right	124	244	110	914.4013
2	Male	Recv 30	2	Left	116	236	107	
2	Male	Recv 30	3	Right	83	240	103	933.0063
2	Male	Recv 30	3	Left	84	237	100	
2	Male	Recv 45	1	Right	94	235	109	957.5643
2	Male	Recv 45	1	Left	90	228	101	
2	Male	Recv 45	2	Right	83	234	108	882.9822
2	Male	Recv 45	2	Left	103	250	124	
2	Male	Recv 45	3	Right	99	221	81	910.8871
2	Male	Recv 45	3	Left	75	256	114	
2	Male	Recv 60	1	Right	93	234	107	875.5657
2	Male	Recv 60	1	Left	89	227	100	
2	Male	Recv 60	2	Right	82	233	107	882.9822
2	Male	Recv 60	2	Left	102	249	123	
2	Male	Recv 60	3	Right	97	220	80	998.4646
2	Male	Recv 60	3	Left	73	253	113	
3	Female	Pre-Fatigue	1	Right	75	276	131	932.115
3	Female	Pre-Fatigue	1	Left	71	278	133	
3	Female	Pre-Fatigue	2	Right	84	297	153	825.2603
3	Female	Pre-Fatigue	2	Left	89	281	137	

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
3	Female	Pre-Fatigue	3	Right	94	267	126	831.8612
3	Female	Pre-Fatigue	3	Left	97	274	133	
3	Female	Post-Fatigue	1	Right	76	233	89	598.7883
3	Female	Post-Fatigue	1	Left	93	245	101	
3	Female	Post-Fatigue	2	Right	98	336	194	639.6602
3	Female	Post-Fatigue	2	Left	95	352	210	
3	Female	Post-Fatigue	3	Right	133	389	200	761.7804
3	Female	Post-Fatigue	3	Left	133	412	223	
3	Female	Recv 15	1	Right	84	277	133	913.721
3	Female	Recv 15	1	Left	89	283	139	
3	Female	Recv 15	2	Right	84	294	139	811.6927
3	Female	Recv 15	2	Left	85	291	136	
3	Female	Recv 15	3	Right	87	279	137	790.6941
3	Female	Recv 15	3	Left	89	288	136	
3	Female	Recv 30	1	Right	95	280	137	827.1099
3	Female	Recv 30	1	Left	93	282	139	
3	Female	Recv 30	2	Right	78	273	134	866.6762
3	Female	Recv 30	2	Left	73	275	136	
3	Female	Recv 30	3	Right	88	288	133	852.1866
3	Female	Recv 30	3	Left	86	291	136	
3	Female	Recv 45	1	Right	74	275	132	890.6754
3	Female	Recv 45	1	Left	70	277	133	
3	Female	Recv 45	2	Right	83	300	153	834.5419
3	Female	Recv 45	2	Left	88	280	137	
3	Female	Recv 45	3	Right	95	266	126	862.6087
3	Female	Recv 45	3	Left	98	273	133	
3	Female	Recv 60	1	Right	75	275	131	911.8375
3	Female	Recv 60	1	Left	71	277	132	
3	Female	Recv 60	2	Right	84	296	152	795.4738
3	Female	Recv 60	2	Left	89	280	138	
3	Female	Recv 60	3	Right	93	266	126	882.6087
3	Female	Recv 60	3	Left	96	273	133	
4	Male	Pre-Fatigue	1	Right	82	231	104	836.4114
4	Male	Pre-Fatigue	1	Left	82	234	107	
4	Male	Pre-Fatigue	2	Right	85	236	110	900.6198
4	Male	Pre-Fatigue	2	Left	77	239	113	
4	Male	Pre-Fatigue	3	Right	93	237	110	785.0199
4	Male	Pre-Fatigue	3	Left	97	234	107	
4	Male	Post-Fatigue	1	Right	87	317	157	727.5833
4	Male	Post-Fatigue	1	Left	84	304	154	
4	Male	Post-Fatigue	2	Right	78	321	157	666.8017

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
4	Male	Post-Fatigue	2	Left	82	316	172	
4	Male	Post-Fatigue	3	Right	251	234	148	737.9227
4	Male	Post-Fatigue	3	Left	245	289	173	
4	Male	Recv 15	1	Right	90	245	106	821.7973
4	Male	Recv 15	1	Left	85	242	113	
4	Male	Recv 15	2	Right	90	245	111	803.693
4	Male	Recv 15	2	Left	85	242	108	
4	Male	Recv 15	3	Right	90	255	111	843.4777
4	Male	Recv 15	3	Left	85	252	108	
4	Male	Recv 30	1	Right	83	246	113	963.3966
4	Male	Recv 30	1	Left	82	247	114	
4	Male	Recv 30	2	Right	88	230	100	759.8773
4	Male	Recv 30	2	Left	90	227	97	
4	Male	Recv 30	3	Right	89	250	119	768.1604
4	Male	Recv 30	3	Left	88	242	111	
4	Male	Recv 45	1	Right	83	231	105	770.6782
4	Male	Recv 45	1	Left	83	234	107	
4	Male	Recv 45	2	Right	86	236	110	954.7221
4	Male	Recv 45	2	Left	78	239	113	
4	Male	Recv 45	3	Right	94	237	110	793.3321
4	Male	Recv 45	3	Left	98	234	107	
4	Male	Recv 60	1	Right	82	230	103	857.5647
4	Male	Recv 60	1	Left	82	233	106	
4	Male	Recv 60	2	Right	85	235	109	831.5648
4	Male	Recv 60	2	Left	77	238	112	
4	Male	Recv 60	3	Right	92	236	109	844.0295
4	Male	Recv 60	3	Left	96	233	106	
5	Female	Pre-Fatigue	1	Right	127	315	167	823.0945
5	Female	Pre-Fatigue	1	Left	117	315	167	
5	Female	Pre-Fatigue	2	Right	146	294	157	924.8633
5	Female	Pre-Fatigue	2	Left	149	289	152	
5	Female	Pre-Fatigue	3	Right	106	235	92	697.399
5	Female	Pre-Fatigue	3	Left	98	241	98	
5	Female	Post-Fatigue	1	Right	173	353	208	672.5602
5	Female	Post-Fatigue	1	Left	191	346	201	
5	Female	Post-Fatigue	2	Right	169	300	162	717.9735
5	Female	Post-Fatigue	2	Left	174	291	153	
5	Female	Post-Fatigue	3	Right	148	511	374	719.8431
5	Female	Post-Fatigue	3	Left	139	491	354	
5	Female	Recv 15	1	Right	140	333	147	797.621
5	Female	Recv 15	1	Left	119	332	146	

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
5	Female	Recv 15	2	Right	136	284	152	791.4575
5	Female	Recv 15	2	Left	136	283	151	
5	Female	Recv 15	3	Right	113	295	157	809.7455
5	Female	Recv 15	3	Left	114	289	151	
5	Female	Recv 30	1	Right	118	268	133	816.6327
5	Female	Recv 30	1	Left	122	264	129	
5	Female	Recv 30	2	Right	118	303	160	693.7056
5	Female	Recv 30	2	Left	121	303	158	
5	Female	Recv 30	3	Right	130	279	141	919.7881
5	Female	Recv 30	3	Left	137	284	146	
5	Female	Recv 45	1	Right	127	317	168	701.7627
5	Female	Recv 45	1	Left	118	317	167	
5	Female	Recv 45	2	Right	146	296	157	834.2981
5	Female	Recv 45	2	Left	151	291	152	
5	Female	Recv 45	3	Right	107	237	92	902.7763
5	Female	Recv 45	3	Left	98	243	98	
5	Female	Recv 60	1	Right	127	314	166	814.5648
5	Female	Recv 60	1	Left	118	314	166	
5	Female	Recv 60	2	Right	146	293	156	910.4647
5	Female	Recv 60	2	Left	150	288	151	
5	Female	Recv 60	3	Right	105	234	91	722.2463
5	Female	Recv 60	3	Left	98	240	97	
6	Male	Pre-Fatigue	1	Right	78	175	42	914.3305
6	Male	Pre-Fatigue	1	Left	67	181	48	
6	Male	Pre-Fatigue	2	Right	52	136	51	964.8537
6	Male	Pre-Fatigue	2	Left	70	173	68	
6	Male	Pre-Fatigue	3	Right	68	200	65	906.206
6	Male	Pre-Fatigue	3	Left	68	198	63	
6	Male	Post-Fatigue	1	Right	90	257	123	752.7497
6	Male	Post-Fatigue	1	Left	73	260	126	
6	Male	Post-Fatigue	2	Right	95	263	127	783.1428
6	Male	Post-Fatigue	2	Left	90	273	137	
6	Male	Post-Fatigue	3	Right	98	255	125	758.3329
6	Male	Post-Fatigue	3	Left	94	255	125	
6	Male	Recv 15	1	Right	74	176	51	901.78
6	Male	Recv 15	1	Left	71	182	57	
6	Male	Recv 15	2	Right	60	193	64	930.112
6	Male	Recv 15	2	Left	67	193	64	
6	Male	Recv 15	3	Right	74	179	56	892.1991
6	Male	Recv 15	3	Left	73	175	52	
6	Male	Recv 30	1	Right	76	174	53	869.3138

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
6	Male	Recv 30	1	Left	71	176	52	
6	Male	Recv 30	2	Right	75	192	65	1079.14
6	Male	Recv 30	2	Left	74	192	65	
6	Male	Recv 30	3	Right	57	175	52	824.9658
6	Male	Recv 30	3	Left	56	176	53	
6	Male	Recv 45	1	Right	79	176	42	936.2214
6	Male	Recv 45	1	Left	67	182	48	
6	Male	Recv 45	2	Right	52	137	51	903.9973
6	Male	Recv 45	2	Left	71	174	68	
6	Male	Recv 45	3	Right	68	201	65	947.2121
6	Male	Recv 45	3	Left	68	199	63	
6	Male	Recv 60	1	Right	80	174	41	951.5647
6	Male	Recv 60	1	Left	67	180	48	
6	Male	Recv 60	2	Right	52	135	52	906.5937
6	Male	Recv 60	2	Left	71	172	69	
6	Male	Recv 60	3	Right	67	199	66	927.7348
6	Male	Recv 60	3	Left	67	197	62	
7	Female	Pre-Fatigue	1	Right	76	182	84	914.2517
7	Female	Pre-Fatigue	1	Left	87	176	78	
7	Female	Pre-Fatigue	2	Right	129	256	103	908.0091
7	Female	Pre-Fatigue	2	Left	111	253	100	
7	Female	Pre-Fatigue	3	Right	126	244	114	951.7517
7	Female	Pre-Fatigue	3	Left	138	230	100	
7	Female	Post-Fatigue	1	Right	124	244	111	803.4409
7	Female	Post-Fatigue	1	Left	120	233	100	
7	Female	Post-Fatigue	2	Right	101	380	251	795.086
7	Female	Post-Fatigue	2	Left	116	383	254	
7	Female	Post-Fatigue	3	Right	126	553	367	804.8037
7	Female	Post-Fatigue	3	Left	139	503	317	
7	Female	Recv 15	1	Right	111	247	99	861.2757
7	Female	Recv 15	1	Left	112	245	97	
7	Female	Recv 15	2	Right	113	196	126	803.2178
7	Female	Recv 15	2	Left	114	209	139	
7	Female	Recv 15	3	Right	114	260	99	1053.98
7	Female	Recv 15	3	Left	115	250	89	
7	Female	Recv 30	1	Right	109	238	89	978.6353
7	Female	Recv 30	1	Left	111	241	92	
7	Female	Recv 30	2	Right	112	227	94	874.5032
7	Female	Recv 30	2	Left	111	233	100	
7	Female	Recv 30	3	Right	114	222	107	911.655
7	Female	Recv 30	3	Left	115	223	108	

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
7	Female	Recv 45	1	Right	76	183	84	943.2374
7	Female	Recv 45	1	Left	88	177	78	
7	Female	Recv 45	2	Right	129	258	103	902.5544
7	Female	Recv 45	2	Left	111	255	100	
7	Female	Recv 45	3	Right	126	246	114	926.8972
7	Female	Recv 45	3	Left	138	232	100	
7	Female	Recv 60	1	Right	76	181	83	931.3829
7	Female	Recv 60	1	Left	87	175	77	
7	Female	Recv 60	2	Right	129	255	102	966.4538
7	Female	Recv 60	2	Left	111	252	99	
7	Female	Recv 60	3	Right	126	243	113	875.2837
7	Female	Recv 60	3	Left	138	229	99	
8	Male	Pre-Fatigue	1	Right	134	279	131	1103.222
8	Male	Pre-Fatigue	1	Left	168	301	153	
8	Male	Pre-Fatigue	2	Right	135	327	164	1038.66
8	Male	Pre-Fatigue	2	Left	110	341	178	
8	Male	Pre-Fatigue	3	Right	145	269	123	1036.36
8	Male	Pre-Fatigue	3	Left	142	270	124	
8	Male	Post-Fatigue	1	Right	156	421	268	985.0485
8	Male	Post-Fatigue	1	Left	173	395	242	
8	Male	Post-Fatigue	2	Right	152	315	164	962.2552
8	Male	Post-Fatigue	2	Left	148	342	191	
8	Male	Post-Fatigue	3	Right	159	461	203	945.368
8	Male	Post-Fatigue	3	Left	146	378	270	
8	Male	Recv 15	1	Right	140	289	148	1029.793
8	Male	Recv 15	1	Left	148	303	146	
8	Male	Recv 15	2	Right	143	308	147	1057.697
8	Male	Recv 15	2	Left	133	303	142	
8	Male	Recv 15	3	Right	140	304	143	1053.325
8	Male	Recv 15	3	Left	141	295	154	
8	Male	Recv 30	1	Right	153	315	143	1012.489
8	Male	Recv 30	1	Left	144	317	145	
8	Male	Recv 30	2	Right	131	290	147	1111.21
8	Male	Recv 30	2	Left	132	285	152	
8	Male	Recv 30	3	Right	138	292	143	1036.507
8	Male	Recv 30	3	Left	140	293	144	
8	Male	Recv 45	1	Right	134	281	132	1083.664
8	Male	Recv 45	1	Left	168	303	153	
8	Male	Recv 45	2	Right	135	329	164	997.4649
8	Male	Recv 45	2	Left	110	344	178	
8	Male	Recv 45	3	Right	145	271	123	1093.466

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
8	Male	Recv 45	3	Left	142	272	124	
8	Male	Recv 60	1	Right	138	278	130	1052.635
8	Male	Recv 60	1	Left	168	304	152	
8	Male	Recv 60	2	Right	134	330	163	1088.467
8	Male	Recv 60	2	Left	110	340	177	
8	Male	Recv 60	3	Right	144	269	122	1041.454
8	Male	Recv 60	3	Left	141	269	123	
9	Female	Pre-Fatigue	1	Right	86	186	52	1062.378
9	Female	Pre-Fatigue	1	Left	90	204	70	
9	Female	Pre-Fatigue	2	Right	116	223	84	1090.458
9	Female	Pre-Fatigue	2	Left	99	251	112	
9	Female	Pre-Fatigue	3	Right	72	269	103	1052.986
9	Female	Pre-Fatigue	3	Left	90	253	87	
9	Female	Post-Fatigue	1	Right	103	266	109	916.1532
9	Female	Post-Fatigue	1	Left	98	296	139	
9	Female	Post-Fatigue	2	Right	98	266	102	899.6379
9	Female	Post-Fatigue	2	Left	101	267	103	
9	Female	Post-Fatigue	3	Right	115	324	168	889.0036
9	Female	Post-Fatigue	3	Left	112	296	140	
9	Female	Recv 15	1	Right	96	244	83	1044.189
9	Female	Recv 15	1	Left	94	236	85	
9	Female	Recv 15	2	Right	93	229	84	1053.358
9	Female	Recv 15	2	Left	92	225	80	
9	Female	Recv 15	3	Right	92	231	92	1046.114
9	Female	Recv 15	3	Left	92	230	91	
9	Female	Recv 30	1	Right	95	235	87	1020.521
9	Female	Recv 30	1	Left	93	233	85	
9	Female	Recv 30	2	Right	84	236	81	1069.236
9	Female	Recv 30	2	Left	74	239	84	
9	Female	Recv 30	3	Right	105	220	84	1082.517
9	Female	Recv 30	3	Left	106	226	90	
9	Female	Recv 45	1	Right	87	187	52	1003.674
9	Female	Recv 45	1	Left	89	205	70	
9	Female	Recv 45	2	Right	117	226	84	1078.454
9	Female	Recv 45	2	Left	98	250	112	
9	Female	Recv 45	3	Right	72	269	103	1122.274
9	Female	Recv 45	3	Left	89	252	87	
9	Female	Recv 60	1	Right	86	185	51	1093.365
9	Female	Recv 60	1	Left	90	203	69	
9	Female	Recv 60	2	Right	116	222	83	1122.835
9	Female	Recv 60	2	Left	99	250	111	

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
9	Female	Recv 60	3	Right	72	268	102	985.3747
9	Female	Recv 60	3	Left	89	252	86	
10	Male	Pre-Fatigue	1	Right	73	224	113	1007.882
10	Male	Pre-Fatigue	1	Left	75	267	123	
10	Male	Pre-Fatigue	2	Right	76	239	126	993.6125
10	Male	Pre-Fatigue	2	Left	83	273	126	
10	Male	Pre-Fatigue	3	Right	70	324	110	1046.558
10	Male	Pre-Fatigue	3	Left	75	271	124	
10	Male	Post-Fatigue	1	Right	165	319	208	888.3071
10	Male	Post-Fatigue	1	Left	146	336	207	
10	Male	Post-Fatigue	2	Right	145	371	200	782.2673
10	Male	Post-Fatigue	2	Left	154	369	203	
10	Male	Post-Fatigue	3	Right	160	357	213	948.8427
10	Male	Post-Fatigue	3	Left	157	335	204	
10	Male	Recv 15	1	Right	95	281	139	1009.075
10	Male	Recv 15	1	Left	81	285	143	
10	Male	Recv 15	2	Right	87	277	122	992.5923
10	Male	Recv 15	2	Left	89	275	120	
10	Male	Recv 15	3	Right	75	254	107	1006.278
10	Male	Recv 15	3	Left	70	268	113	
10	Male	Recv 30	1	Right	78	268	114	999.0339
10	Male	Recv 30	1	Left	80	265	111	
10	Male	Recv 30	2	Right	76	270	129	1064.388
10	Male	Recv 30	2	Left	81	272	137	
10	Male	Recv 30	3	Right	74	264	113	954.3892
10	Male	Recv 30	3	Left	77	280	129	
10	Male	Recv 45	1	Right	74	226	114	983.2627
10	Male	Recv 45	1	Left	76	269	123	
10	Male	Recv 45	2	Right	77	241	126	1045.364
10	Male	Recv 45	2	Left	84	275	126	
10	Male	Recv 45	3	Right	71	326	110	1014.313
10	Male	Recv 45	3	Left	76	273	124	
10	Male	Recv 60	1	Right	73	223	112	1033.329
10	Male	Recv 60	1	Left	75	266	122	
10	Male	Recv 60	2	Right	76	238	125	997.4546
10	Male	Recv 60	2	Left	83	272	125	
10	Male	Recv 60	3	Right	69	323	109	1022.032
10	Male	Recv 60	3	Left	74	270	123	
11	Female	Pre-Fatigue	1	Right	124	266	68	979.3051
11	Female	Pre-Fatigue	1	Left	102	251	83	
11	Female	Pre-Fatigue	2	Right	96	238	76	980.7164

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
11	Female	Pre-Fatigue	2	Left	112	261	99	
11	Female	Pre-Fatigue	3	Right	111	219	75	956.3841
11	Female	Pre-Fatigue	3	Left	106	232	88	
11	Female	Post-Fatigue	1	Right	175	426	278	751.6706
11	Female	Post-Fatigue	1	Left	178	422	274	
11	Female	Post-Fatigue	2	Right	187	434	287	808.1905
11	Female	Post-Fatigue	2	Left	187	398	251	
11	Female	Post-Fatigue	3	Right	104	335	197	891.7172
11	Female	Post-Fatigue	3	Left	109	335	197	
11	Female	Recv 15	1	Right	86	268	78	961.683
11	Female	Recv 15	1	Left	107	271	81	
11	Female	Recv 15	2	Right	119	233	81	968.1173
11	Female	Recv 15	2	Left	102	208	86	
11	Female	Recv 15	3	Right	126	259	87	932.3479
11	Female	Recv 15	3	Left	129	258	86	
11	Female	Recv 30	1	Right	91	245	78	985.4588
11	Female	Recv 30	1	Left	95	246	79	
11	Female	Recv 30	2	Right	107	235	79	1022.939
11	Female	Recv 30	2	Left	113	232	76	
11	Female	Recv 30	3	Right	133	252	86	899.7989
11	Female	Recv 30	3	Left	120	263	97	
11	Female	Recv 45	1	Right	125	268	68	933.4655
11	Female	Recv 45	1	Left	103	253	83	
11	Female	Recv 45	2	Right	97	240	76	976.3544
11	Female	Recv 45	2	Left	113	263	99	
11	Female	Recv 45	3	Right	112	220	75	1003.476
11	Female	Recv 45	3	Left	107	234	88	
11	Female	Recv 60	1	Right	124	265	67	947.3737
11	Female	Recv 60	1	Left	102	250	82	
11	Female	Recv 60	2	Right	96	237	75	963.6748
11	Female	Recv 60	2	Left	112	260	98	
11	Female	Recv 60	3	Right	110	218	74	1004.647
11	Female	Recv 60	3	Left	105	231	87	
12	Male	Pre-Fatigue	1	Right	96	195	39	1047.943
12	Male	Pre-Fatigue	1	Left	74	182	26	
12	Male	Pre-Fatigue	2	Right	90	165	26	1084.788
12	Male	Pre-Fatigue	2	Left	99	184	45	
12	Male	Pre-Fatigue	3	Right	86	172	27	1050.386
12	Male	Pre-Fatigue	3	Left	82	176	31	
12	Male	Post-Fatigue	1	Right	141	351	113	901.5185
12	Male	Post-Fatigue	1	Left	168	324	116	

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
12	Male	Post-Fatigue	2	Right	142	325	136	934.8095
12	Male	Post-Fatigue	2	Left	134	326	117	
12	Male	Post-Fatigue	3	Right	215	309	147	889.878
12	Male	Post-Fatigue	3	Left	206	282	110	
12	Male	Recv 15	1	Right	109	192	46	1068.674
12	Male	Recv 15	1	Left	111	196	50	
12	Male	Recv 15	2	Right	101	239	56	1064.347
12	Male	Recv 15	2	Left	103	235	52	
12	Male	Recv 15	3	Right	82	184	45	1006.278
12	Male	Recv 15	3	Left	84	182	43	
12	Male	Recv 30	1	Right	92	201	42	1038.472
12	Male	Recv 30	1	Left	82	195	36	
12	Male	Recv 30	2	Right	92	195	28	1057.317
12	Male	Recv 30	2	Left	94	201	34	
12	Male	Recv 30	3	Right	100	196	42	1078.977
12	Male	Recv 30	3	Left	87	201	47	
12	Male	Recv 45	1	Right	97	196	39	1121.466
12	Male	Recv 45	1	Left	75	183	26	
12	Male	Recv 45	2	Right	91	166	26	910.2645
12	Male	Recv 45	2	Left	100	185	45	
12	Male	Recv 45	3	Right	87	173	27	1145.475
12	Male	Recv 45	3	Left	83	177	31	
12	Male	Recv 60	1	Right	96	194	38	1201.454
12	Male	Recv 60	1	Left	75	181	25	
12	Male	Recv 60	2	Right	91	164	25	915.3537
12	Male	Recv 60	2	Left	99	183	44	
12	Male	Recv 60	3	Right	86	171	26	1074.264
12	Male	Recv 60	3	Left	82	175	30	
13	Female	Pre-Fatigue	1	Right	78	246	105	934.6992
13	Female	Pre-Fatigue	1	Left	78	221	80	
13	Female	Pre-Fatigue	3	Right	76	173	34	901.2414
13	Female	Pre-Fatigue	3	Left	79	195	56	
13	Female	Pre-Fatigue	4	Right	61	171	20	1058.944
13	Female	Pre-Fatigue	4	Left	53	164	13	
13	Female	Post-Fatigue	1	Right	109	282	122	883.8113
13	Female	Post-Fatigue	1	Left	113	318	158	
13	Female	Post-Fatigue	2	Right	113	255	117	835.032
13	Female	Post-Fatigue	2	Left	105	242	104	
13	Female	Post-Fatigue	3	Right	114	310	161	841.9519
13	Female	Post-Fatigue	3	Left	106	296	147	
13	Female	Recv 15	1	Right	83	217	62	1080.911

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
13	Female	Recv 15	1	Left	85	211	56	
13	Female	Recv 15	2	Right	83	222	70	1021.915
13	Female	Recv 15	2	Left	77	222	70	
13	Female	Recv 15	3	Right	64	188	52	763.9978
13	Female	Recv 15	3	Left	66	190	54	
13	Female	Recv 30	1	Right	73	204	52	901.2818
13	Female	Recv 30	1	Left	67	203	51	
13	Female	Recv 30	2	Right	83	212	52	1022.504
13	Female	Recv 30	2	Left	73	217	57	
13	Female	Recv 30	3	Right	79	189	71	961.8929
13	Female	Recv 30	3	Left	73	197	69	
13	Female	Recv 45	1	Right	79	248	106	975.5647
13	Female	Recv 45	1	Left	79	223	80	
13	Female	Recv 45	2	Right	77	174	34	893.5647
13	Female	Recv 45	2	Left	80	196	56	
13	Female	Recv 45	3	Right	61	172	20	1017.455
13	Female	Recv 45	3	Left	53	165	13	
13	Female	Recv 60	1	Right	78	248	104	1088.354
13	Female	Recv 60	1	Left	78	223	79	
13	Female	Recv 60	2	Right	76	174	33	793.6753
13	Female	Recv 60	2	Left	80	196	55	
13	Female	Recv 60	3	Right	61	170	19	1012.483
13	Female	Recv 60	3	Left	53	163	12	
14	Male	Pre-Fatigue	1	Right	138	259	123	1180.124
14	Male	Pre-Fatigue	1	Left	128	271	135	
14	Male	Pre-Fatigue	2	Right	134	251	111	1069.181
14	Male	Pre-Fatigue	2	Left	139	256	116	
14	Male	Pre-Fatigue	3	Right	125	255	104	1040.959
14	Male	Pre-Fatigue	3	Left	138	278	127	
14	Male	Post-Fatigue	1	Right	136	394	240	994.7369
14	Male	Post-Fatigue	1	Left	127	401	256	
14	Male	Post-Fatigue	2	Right	185	402	262	1030.658
14	Male	Post-Fatigue	2	Left	187	398	259	
14	Male	Post-Fatigue	3	Right	176	374	235	805.5694
14	Male	Post-Fatigue	3	Left	184	370	221	
14	Male	Recv 15	1	Right	139	277	131	1149.57
14	Male	Recv 15	1	Left	134	277	131	
14	Male	Recv 15	2	Right	126	309	122	1021.677
14	Male	Recv 15	2	Left	127	309	122	
14	Male	Recv 15	3	Right	139	297	138	1066.268
14	Male	Recv 15	3	Left	139	301	142	

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
14	Male	Recv 30	1	Right	135	292	142	1132.074
14	Male	Recv 30	1	Left	129	283	133	
14	Male	Recv 30	2	Right	122	280	126	1054.667
14	Male	Recv 30	2	Left	128	277	123	
14	Male	Recv 30	3	Right	153	264	117	1080.346
14	Male	Recv 30	3	Left	135	263	116	
14	Male	Recv 45	1	Right	138	260	124	1201.232
14	Male	Recv 45	1	Left	128	272	135	
14	Male	Recv 45	2	Right	134	252	111	1004.466
14	Male	Recv 45	2	Left	139	257	116	
14	Male	Recv 45	3	Right	125	256	104	1079.164
14	Male	Recv 45	3	Left	140	280	127	
14	Male	Recv 60	1	Right	138	258	122	1172.175
14	Male	Recv 60	1	Left	128	270	134	
14	Male	Recv 60	2	Right	135	250	110	1193.465
14	Male	Recv 60	2	Left	140	255	115	
14	Male	Recv 60	3	Right	125	254	103	932.4674
14	Male	Recv 60	3	Left	137	277	126	
15	Female	Pre-Fatigue	1	Right	85	140	67	856.5254
15	Female	Pre-Fatigue	1	Left	96	155	82	
15	Female	Pre-Fatigue	2	Right	80	199	64	860.2892
15	Female	Pre-Fatigue	2	Left	70	176	41	
15	Female	Pre-Fatigue	3	Right	88	192	44	920.7052
15	Female	Pre-Fatigue	3	Left	81	187	39	
15	Female	Post-Fatigue	1	Right	114	225	75	751.3783
15	Female	Post-Fatigue	1	Left	106	235	94	
15	Female	Post-Fatigue	2	Right	96	190	57	783.9398
15	Female	Post-Fatigue	2	Left	80	198	65	
15	Female	Post-Fatigue	3	Right	103	248	93	738.0044
15	Female	Post-Fatigue	3	Left	132	278	123	
15	Female	Recv 15	1	Right	93	199	79	785.0954
15	Female	Recv 15	1	Left	77	182	62	
15	Female	Recv 15	2	Right	81	194	53	837.8787
15	Female	Recv 15	2	Left	83	197	56	
15	Female	Recv 15	3	Right	89	172	72	988.5314
15	Female	Recv 15	3	Left	89	169	69	
15	Female	Recv 30	1	Right	83	190	53	901.2301
15	Female	Recv 30	1	Left	82	190	53	
15	Female	Recv 30	2	Right	92	148	54	871.33
15	Female	Recv 30	2	Left	94	150	56	
15	Female	Recv 30	3	Right	78	222	69	843.91

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
15	Female	Recv 30	3	Left	76	207	74	
15	Female	Recv 45	1	Right	85	141	67	901.5665
15	Female	Recv 45	1	Left	96	156	82	
15	Female	Recv 45	2	Right	80	200	67	824.4546
15	Female	Recv 45	2	Left	70	177	41	
15	Female	Recv 45	3	Right	88	193	44	912.1546
15	Female	Recv 45	3	Left	81	188	39	
15	Female	Recv 60	1	Right	85	140	66	942.4637
15	Female	Recv 60	1	Left	96	158	81	
15	Female	Recv 60	2	Right	80	199	63	802.5648
15	Female	Recv 60	2	Left	70	176	45	
15	Female	Recv 60	3	Right	87	192	43	890.2547
15	Female	Recv 60	3	Left	80	187	38	
16	Male	Pre-Fatigue	1	Right	97	223	71	1029.43
16	Male	Pre-Fatigue	1	Left	93	236	84	
16	Male	Pre-Fatigue	2	Right	115	231	67	1064.429
16	Male	Pre-Fatigue	2	Left	114	224	60	
16	Male	Pre-Fatigue	3	Right	76	213	70	1003.68
16	Male	Pre-Fatigue	3	Left	76	232	71	
16	Male	Post-Fatigue	1	Right	117	289	150	829.1794
16	Male	Post-Fatigue	1	Left	113	275	136	
16	Male	Post-Fatigue	2	Right	110	329	164	827.3386
16	Male	Post-Fatigue	2	Left	115	354	189	
16	Male	Post-Fatigue	3	Right	87	261	112	845.6983
16	Male	Post-Fatigue	3	Left	87	252	103	
16	Male	Recv 15	1	Right	89	230	99	1040.638
16	Male	Recv 15	1	Left	84	231	100	
16	Male	Recv 15	2	Right	102	253	74	1015.688
16	Male	Recv 15	2	Left	95	251	72	
16	Male	Recv 15	3	Right	97	228	75	937.0392
16	Male	Recv 15	3	Left	106	228	85	
16	Male	Recv 30	1	Right	105	238	77	1009.316
16	Male	Recv 30	1	Left	92	238	77	
16	Male	Recv 30	2	Right	99	225	73	987.554
16	Male	Recv 30	2	Left	95	229	77	
16	Male	Recv 30	3	Right	91	213	77	1014.024
16	Male	Recv 30	3	Left	89	217	81	
16	Male	Recv 45	1	Right	97	225	71	910.7547
16	Male	Recv 45	1	Left	92	238	84	
16	Male	Recv 45	2	Right	115	233	67	1085.454
16	Male	Recv 45	2	Left	114	226	60	

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
16	Male	Recv 45	3	Right	76	214	70	1095.383
16	Male	Recv 45	3	Left	76	234	71	
16	Male	Recv 60	1	Right	97	223	70	1103.546
16	Male	Recv 60	1	Left	93	236	83	
16	Male	Recv 60	2	Right	114	233	66	966.4528
16	Male	Recv 60	2	Left	116	226	59	
16	Male	Recv 60	3	Right	76	212	69	1048.657
16	Male	Recv 60	3	Left	76	231	70	
17	Female	Pre-Fatigue	1	Right	112	269	98	1119.86
17	Female	Pre-Fatigue	1	Left	103	276	105	
17	Female	Pre-Fatigue	2	Right	99	283	112	1009.739
17	Female	Pre-Fatigue	2	Left	109	279	108	
17	Female	Pre-Fatigue	3	Right	99	254	116	1057.972
17	Female	Pre-Fatigue	3	Left	76	226	88	
17	Female	Post-Fatigue	1	Right	106	325	163	827.1101
17	Female	Post-Fatigue	1	Left	109	311	149	
17	Female	Post-Fatigue	2	Right	186	340	156	911.09
17	Female	Post-Fatigue	2	Left	166	331	147	
17	Female	Post-Fatigue	3	Right	136	371	238	879.1135
17	Female	Post-Fatigue	3	Left	135	366	233	
17	Female	Recv 15	1	Right	100	265	105	1003.453
17	Female	Recv 15	1	Left	103	267	107	
17	Female	Recv 15	2	Right	95	266	106	1019.789
17	Female	Recv 15	2	Left	85	261	101	
17	Female	Recv 15	3	Right	126	278	115	1035.71
17	Female	Recv 15	3	Left	129	268	105	
17	Female	Recv 30	1	Right	104	285	108	1074.843
17	Female	Recv 30	1	Left	98	272	95	
17	Female	Recv 30	2	Right	104	255	104	1081.471
17	Female	Recv 30	2	Left	96	261	110	
17	Female	Recv 30	3	Right	95	258	103	987.1759
17	Female	Recv 30	3	Left	113	266	111	
17	Female	Recv 45	1	Right	111	271	98	1042.263
17	Female	Recv 45	1	Left	102	278	105	
17	Female	Recv 45	2	Right	100	285	112	1033.817
17	Female	Recv 45	2	Left	110	281	108	
17	Female	Recv 45	3	Right	100	256	116	1104.365
17	Female	Recv 45	3	Left	77	223	88	
17	Female	Recv 60	1	Right	112	268	97	1161.474
17	Female	Recv 60	1	Left	103	275	104	
17	Female	Recv 60	2	Right	99	282	111	943.4678

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
17	Female	Recv 60	2	Left	109	278	107	
17	Female	Recv 60	3	Right	98	250	115	1081.565
17	Female	Recv 60	3	Left	75	223	87	
18	Male	Pre-Fatigue	1	Right	77	155	18	950.9915
18	Male	Pre-Fatigue	1	Left	72	158	21	
18	Male	Pre-Fatigue	2	Right	95	200	29	1029.594
18	Male	Pre-Fatigue	2	Left	97	198	27	
18	Male	Pre-Fatigue	3	Right	87	168	18	1005.82
18	Male	Pre-Fatigue	3	Left	103	169	19	
18	Male	Post-Fatigue	1	Right	106	254	126	838.3513
18	Male	Post-Fatigue	1	Left	103	248	120	
18	Male	Post-Fatigue	2	Right	79	254	119	868.901
18	Male	Post-Fatigue	2	Left	90	261	126	
18	Male	Post-Fatigue	3	Right	107	250	113	825.803
18	Male	Post-Fatigue	3	Left	102	250	113	
18	Male	Recv 15	1	Right	89	162	20	951.6892
18	Male	Recv 15	1	Left	84	164	22	
18	Male	Recv 15	2	Right	95	190	29	972.9979
18	Male	Recv 15	2	Left	97	188	27	
18	Male	Recv 15	3	Right	91	173	19	947.7119
18	Male	Recv 15	3	Left	84	174	20	
18	Male	Recv 30	1	Right	90	182	23	1014.23
18	Male	Recv 30	1	Left	94	178	19	
18	Male	Recv 30	2	Right	86	167	23	887.34
18	Male	Recv 30	2	Left	87	170	26	
18	Male	Recv 30	3	Right	85	176	21	1001.556
18	Male	Recv 30	3	Left	88	177	22	
18	Male	Recv 45	1	Right	76	156	18	928.8374
18	Male	Recv 45	1	Left	71	159	21	
18	Male	Recv 45	2	Right	96	201	29	1048.464
18	Male	Recv 45	2	Left	98	199	27	
18	Male	Recv 45	3	Right	87	169	18	1008.454
18	Male	Recv 45	3	Left	104	170	19	
18	Male	Recv 60	1	Right	74	154	17	1039.546
18	Male	Recv 60	1	Left	79	157	20	
18	Male	Recv 60	2	Right	94	199	28	983.5655
18	Male	Recv 60	2	Left	96	197	26	
18	Male	Recv 60	3	Right	86	167	17	963.9695
18	Male	Recv 60	3	Left	101	168	18	
19	Female	Pre-Fatigue	1	Right	89	172	41	963.7727
19	Female	Pre-Fatigue	1	Left	90	180	49	

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
19	Female	Pre-Fatigue	2	Right	61	165	30	890.991
19	Female	Pre-Fatigue	2	Left	81	175	40	
19	Female	Pre-Fatigue	3	Right	81	200	64	1091.434
19	Female	Pre-Fatigue	3	Left	75	176	40	
19	Female	Post-Fatigue	1	Right	114	374	229	811.142
19	Female	Post-Fatigue	1	Left	105	377	232	
19	Female	Post-Fatigue	2	Right	83	295	170	824.9457
19	Female	Post-Fatigue	2	Left	84	304	179	
19	Female	Post-Fatigue	3	Right	76	382	247	871.4427
19	Female	Post-Fatigue	3	Left	89	352	217	
19	Female	Recv 15	1	Right	88	201	49	940.1298
19	Female	Recv 15	1	Left	89	203	51	
19	Female	Recv 15	2	Right	73	195	53	1006.781
19	Female	Recv 15	2	Left	79	193	51	
19	Female	Recv 15	3	Right	79	182	46	933.1047
19	Female	Recv 15	3	Left	87	167	31	
19	Female	Recv 30	1	Right	72	180	37	888.3057
19	Female	Recv 30	1	Left	84	190	47	
19	Female	Recv 30	2	Right	88	184	41	1076.961
19	Female	Recv 30	2	Left	78	181	38	
19	Female	Recv 30	3	Right	80	196	53	932.4734
19	Female	Recv 30	3	Left	82	193	50	
19	Female	Recv 45	1	Right	89	173	41	872.4658
19	Female	Recv 45	1	Left	90	181	49	
19	Female	Recv 45	2	Right	61	166	30	1105.565
19	Female	Recv 45	2	Left	81	176	40	
19	Female	Recv 45	3	Right	82	201	63	957.5846
19	Female	Recv 45	3	Left	76	177	40	
19	Female	Recv 60	1	Right	89	171	40	1110.823
19	Female	Recv 60	1	Left	90	179	48	
19	Female	Recv 60	2	Right	61	164	29	989.1423
19	Female	Recv 60	2	Left	81	174	39	
19	Female	Recv 60	3	Right	81	199	63	854.8894
19	Female	Recv 60	3	Left	74	175	39	
20	Male	Pre-Fatigue	1	Right	73	285	140	921.29
20	Male	Pre-Fatigue	1	Left	79	294	149	
20	Male	Pre-Fatigue	2	Right	73	238	91	967.8024
20	Male	Pre-Fatigue	2	Left	72	265	118	
20	Male	Pre-Fatigue	3	Right	83	236	98	925.7693
20	Male	Pre-Fatigue	3	Left	85	230	92	
20	Male	Post-Fatigue	1	Right	85	331	167	765.8011

Subject	Gender	Status	Trial	Side	OD	TTP	PTP	Stiffness
20	Male	Post-Fatigue	1	Left	82	333	169	
20	Male	Post-Fatigue	2	Right	144	362	227	756.6445
20	Male	Post-Fatigue	2	Left	151	392	257	
20	Male	Post-Fatigue	3	Right	116	319	163	765.4569
20	Male	Post-Fatigue	3	Left	112	289	173	
20	Male	Recv 15	1	Right	88	281	139	901.0768
20	Male	Recv 15	1	Left	90	260	118	
20	Male	Recv 15	2	Right	84	287	138	897.498
20	Male	Recv 15	2	Left	85	290	141	
20	Male	Recv 15	3	Right	76	260	127	939.0878
20	Male	Recv 15	3	Left	99	244	111	
20	Male	Recv 30	1	Right	79	271	119	934.3345
20	Male	Recv 30	1	Left	80	251	99	
20	Male	Recv 30	2	Right	84	255	110	876.5564
20	Male	Recv 30	2	Left	85	265	120	
20	Male	Recv 30	3	Right	82	275	141	955.776
20	Male	Recv 30	3	Left	78	264	130	
20	Male	Recv 45	1	Right	74	287	141	925.4647
20	Male	Recv 45	1	Left	80	296	149	
20	Male	Recv 45	2	Right	74	240	91	941.5647
20	Male	Recv 45	2	Left	72	267	119	
20	Male	Recv 45	3	Right	82	238	98	943.3547
20	Male	Recv 45	3	Left	86	232	92	
20	Male	Recv 60	1	Right	73	330	140	935.8988
20	Male	Recv 60	1	Left	79	288	149	
20	Male	Recv 60	2	Right	73	228	96	882.66
20	Male	Recv 60	2	Left	72	254	114	
20	Male	Recv 60	3	Right	83	226	98	1003.89
20	Male	Recv 60	3	Left	85	225	92	

Table 62: SP magnitude parameters and effective stiffness data

Subject	Gender	Status	Trial	Side	RA	RG
1	Female	Pre-Fatigue	1	Right	4.0129	0.003785
1	Female	Pre-Fatigue	1	Left	4.9682	0.005936
1	Female	Pre-Fatigue	2	Right	4.0104	0.005724
1	Female	Pre-Fatigue	2	Left	4.6387	0.005102
1	Female	Pre-Fatigue	3	Right	4.0412	0.005731
1	Female	Pre-Fatigue	3	Left	4.7310	0.005467
1	Female	Post-Fatigue	1	Right	3.2398	0.004574
1	Female	Post-Fatigue	1	Left	3.3781	0.003343
1	Female	Post-Fatigue	2	Right	3.2695	0.003278
1	Female	Post-Fatigue	2	Left	3.8994	0.003055
1	Female	Post-Fatigue	3	Right	3.2200	0.002999
1	Female	Post-Fatigue	3	Left	3.5954	0.003087
2	Male	Pre-Fatigue	1	Right	0.2071	0.000186
2	Male	Pre-Fatigue	1	Left	0.1442	0.000144
2	Male	Pre-Fatigue	2	Right	1.1558	0.001101
2	Male	Pre-Fatigue	2	Left	1.6352	0.001336
2	Male	Pre-Fatigue	3	Right	1.3677	0.001374
2	Male	Pre-Fatigue	3	Left	1.3590	0.001328
2	Male	Post-Fatigue	1	Right	0.3140	0.000260
2	Male	Post-Fatigue	1	Left	0.3770	0.000293
2	Male	Post-Fatigue	2	Right	0.1221	0.000134
2	Male	Post-Fatigue	2	Left	0.1683	0.000162
2	Male	Post-Fatigue	3	Right	0.1374	0.000149
2	Male	Post-Fatigue	3	Left	0.1292	0.000142
3	Female	Pre-Fatigue	1	Right	1.8810	0.001716
3	Female	Pre-Fatigue	1	Left	2.5843	0.002147
3	Female	Pre-Fatigue	2	Right	1.8133	0.001666
3	Female	Pre-Fatigue	2	Left	1.6071	0.001582
3	Female	Pre-Fatigue	3	Right	1.4323	0.001387
3	Female	Pre-Fatigue	3	Left	2.0058	0.001773
3	Female	Post-Fatigue	1	Right	1.5251	0.001461
3	Female	Post-Fatigue	1	Left	2.0504	0.002052
3	Female	Post-Fatigue	2	Right	2.3879	0.002021
3	Female	Post-Fatigue	2	Left	3.0305	0.002452
3	Female	Post-Fatigue	3	Right	1.4522	0.001241
3	Female	Post-Fatigue	3	Left	2.4882	0.001898
4	Male	Pre-Fatigue	1	Right	1.8133	0.001802
4	Male	Pre-Fatigue	1	Left	3.0374	0.002928
4	Male	Pre-Fatigue	2	Right	2.5752	0.002332
4	Male	Pre-Fatigue	2	Left	2.2033	0.002234

Subject	Gender	Status	Trial	Side	RA	RG
4	Male	Pre-Fatigue	3	Right	2.4389	0.002220
4	Male	Pre-Fatigue	3	Left	2.1347	0.002156
4	Male	Post-Fatigue	1	Right	1.8970	0.001718
4	Male	Post-Fatigue	1	Left	1.6262	0.001971
4	Male	Post-Fatigue	2	Right	1.5563	0.001517
4	Male	Post-Fatigue	2	Left	1.7343	0.001867
4	Male	Post-Fatigue	3	Right	2.1349	0.001887
4	Male	Post-Fatigue	3	Left	1.9302	0.001968
5	Female	Pre-Fatigue	1	Right	1.2166	0.001342
5	Female	Pre-Fatigue	1	Left	0.9272	0.001157
5	Female	Pre-Fatigue	2	Right	0.8213	0.001140
5	Female	Pre-Fatigue	2	Left	0.7226	0.001100
5	Female	Pre-Fatigue	3	Right	0.8876	0.001089
5	Female	Pre-Fatigue	3	Left	0.6935	0.000955
5	Female	Post-Fatigue	1	Right	0.9867	0.001244
5	Female	Post-Fatigue	1	Left	0.6442	0.001050
5	Female	Post-Fatigue	2	Right	1.3582	0.001591
5	Female	Post-Fatigue	2	Left	1.2370	0.001475
5	Female	Post-Fatigue	3	Right	1.3907	0.001563
5	Female	Post-Fatigue	3	Left	0.8289	0.001384
6	Male	Pre-Fatigue	1	Right	1.5397	0.001517
6	Male	Pre-Fatigue	1	Left	2.7406	0.002255
6	Male	Pre-Fatigue	2	Right	2.2241	0.001933
6	Male	Pre-Fatigue	2	Left	4.6084	0.003424
6	Male	Pre-Fatigue	3	Right	1.5154	0.001533
6	Male	Pre-Fatigue	3	Left	2.0294	0.001781
6	Male	Post-Fatigue	1	Right	1.1570	0.001205
6	Male	Post-Fatigue	1	Left	1.0849	0.001108
6	Male	Post-Fatigue	2	Right	1.1036	0.001166
6	Male	Post-Fatigue	2	Left	1.0793	0.001102
6	Male	Post-Fatigue	3	Right	0.9245	0.001048
6	Male	Post-Fatigue	3	Left	0.9856	0.001013
7	Female	Pre-Fatigue	1	Right	2.7115	0.003060
7	Female	Pre-Fatigue	1	Left	2.5167	0.002794
7	Female	Pre-Fatigue	2	Right	3.4696	0.002867
7	Female	Pre-Fatigue	2	Left	3.0146	0.002468
7	Female	Pre-Fatigue	3	Right	2.0596	0.002173
7	Female	Pre-Fatigue	3	Left	1.9410	0.001961
7	Female	Post-Fatigue	1	Right	1.2638	0.001606
7	Female	Post-Fatigue	1	Left	2.8691	0.002658
7	Female	Post-Fatigue	2	Right	1.7981	0.001986

Subject	Gender	Status	Trial	Side	RA	RG
7	Female	Post-Fatigue	2	Left	1.7051	0.001914
7	Female	Post-Fatigue	3	Right	2.2664	0.001929
7	Female	Post-Fatigue	3	Left	2.4656	0.002039
8	Male	Pre-Fatigue	1	Right	2.2810	0.001057
8	Male	Pre-Fatigue	1	Left	1.7690	0.001261
8	Male	Pre-Fatigue	2	Right	1.8835	0.001020
8	Male	Pre-Fatigue	2	Left	1.8980	0.001587
8	Male	Pre-Fatigue	3	Right	1.8544	0.001064
8	Male	Pre-Fatigue	3	Left	1.6069	0.001543
8	Male	Post-Fatigue	1	Right	1.9445	0.001169
8	Male	Post-Fatigue	1	Left	1.7599	0.001542
8	Male	Post-Fatigue	2	Right	1.6530	0.000960
8	Male	Post-Fatigue	2	Left	1.2986	0.001267
8	Male	Post-Fatigue	3	Right	1.7348	0.000730
8	Male	Post-Fatigue	3	Left	1.2111	0.000911
9	Female	Pre-Fatigue	1	Right	4.1049	0.003483
9	Female	Pre-Fatigue	1	Left	3.0401	0.004202
9	Female	Pre-Fatigue	2	Right	2.1298	0.003136
9	Female	Pre-Fatigue	2	Left	3.0502	0.004246
9	Female	Pre-Fatigue	3	Right	1.4526	0.003777
9	Female	Pre-Fatigue	3	Left	2.6144	0.003342
9	Female	Post-Fatigue	1	Right	1.3925	0.001515
9	Female	Post-Fatigue	1	Left	2.2813	0.003488
9	Female	Post-Fatigue	2	Right	2.3224	0.002249
9	Female	Post-Fatigue	2	Left	2.3932	0.003048
9	Female	Post-Fatigue	3	Right	2.2080	0.002212
9	Female	Post-Fatigue	3	Left	1.6998	0.001896
10	Male	Pre-Fatigue	1	Right	2.3785	0.001773
10	Male	Pre-Fatigue	1	Left	2.4274	0.002021
10	Male	Pre-Fatigue	2	Right	1.4588	0.001366
10	Male	Pre-Fatigue	2	Left	1.7893	0.001591
10	Male	Pre-Fatigue	3	Right	1.9741	0.001507
10	Male	Pre-Fatigue	3	Left	2.6888	0.002104
10	Male	Post-Fatigue	1	Right	0.9029	0.001884
10	Male	Post-Fatigue	1	Left	1.4603	0.003109
10	Male	Post-Fatigue	2	Right	1.3773	0.001220
10	Male	Post-Fatigue	2	Left	1.9714	0.001858
10	Male	Post-Fatigue	3	Right	1.2687	0.002435
10	Male	Post-Fatigue	3	Left	1.7972	0.003694
11	Female	Pre-Fatigue	1	Right	3.5629	0.002452
11	Female	Pre-Fatigue	1	Left	4.2566	0.003013

Subject	Gender	Status	Trial	Side	RA	RG
11	Female	Pre-Fatigue	2	Right	6.3102	0.004314
11	Female	Pre-Fatigue	2	Left	5.9367	0.004271
11	Female	Pre-Fatigue	3	Right	4.5002	0.006900
11	Female	Pre-Fatigue	3	Left	3.2533	0.005508
11	Female	Post-Fatigue	1	Right	2.8408	0.002189
11	Female	Post-Fatigue	1	Left	2.6834	0.002213
11	Female	Post-Fatigue	2	Right	3.6846	0.002850
11	Female	Post-Fatigue	2	Left	2.9077	0.002458
11	Female	Post-Fatigue	3	Right	3.6758	0.003019
11	Female	Post-Fatigue	3	Left	4.0650	0.003389
12	Male	Pre-Fatigue	1	Right	1.5670	0.001399
12	Male	Pre-Fatigue	1	Left	1.3045	0.001166
12	Male	Pre-Fatigue	2	Right	1.4771	0.001702
12	Male	Pre-Fatigue	2	Left	1.3677	0.001369
12	Male	Pre-Fatigue	3	Right	1.8002	0.001689
12	Male	Pre-Fatigue	3	Left	1.4711	0.001401
12	Male	Post-Fatigue	1	Right	0.8181	0.000796
12	Male	Post-Fatigue	1	Left	1.1415	0.000891
12	Male	Post-Fatigue	2	Right	0.7716	0.000906
12	Male	Post-Fatigue	2	Left	0.7555	0.000822
12	Male	Post-Fatigue	3	Right	0.4680	0.000857
12	Male	Post-Fatigue	3	Left	0.7674	0.000933
13	Female	Pre-Fatigue	1	Right	3.5888	0.003567
13	Female	Pre-Fatigue	1	Left	3.4511	0.004826
13	Female	Pre-Fatigue	2	Right	1.8303	0.001744
13	Female	Pre-Fatigue	2	Left	2.8023	0.002571
13	Female	Pre-Fatigue	3	Right	1.2019	0.002322
13	Female	Pre-Fatigue	3	Left	2.6438	0.004151
13	Female	Post-Fatigue	1	Right	1.9136	0.002123
13	Female	Post-Fatigue	1	Left	1.9733	0.002125
13	Female	Post-Fatigue	2	Right	2.1862	0.002364
13	Female	Post-Fatigue	2	Left	1.5068	0.001996
13	Female	Post-Fatigue	3	Right	2.4336	0.002496
13	Female	Post-Fatigue	3	Left	2.6781	0.002784
14	Male	Pre-Fatigue	1	Right	2.4554	0.002176
14	Male	Pre-Fatigue	1	Left	3.2731	0.002936
14	Male	Pre-Fatigue	2	Right	2.2488	0.002848
14	Male	Pre-Fatigue	2	Left	2.9293	0.002490
14	Male	Pre-Fatigue	3	Right	2.7320	0.002151
14	Male	Pre-Fatigue	3	Left	2.3672	0.002179
14	Male	Post-Fatigue	1	Right	2.1958	0.001822

Subject	Gender	Status	Trial	Side	RA	RG
14	Male	Post-Fatigue	1	Left	2.6431	0.002184
14	Male	Post-Fatigue	2	Right	2.1507	0.002543
14	Male	Post-Fatigue	2	Left	2.8085	0.002045
14	Male	Post-Fatigue	3	Right	2.4348	0.002015
14	Male	Post-Fatigue	3	Left	2.4131	0.002054
15	Female	Pre-Fatigue	1	Right	2.2857	0.002014
15	Female	Pre-Fatigue	1	Left	3.1789	0.002668
15	Female	Pre-Fatigue	2	Right	4.4158	0.003607
15	Female	Pre-Fatigue	2	Left	2.2461	0.002110
15	Female	Pre-Fatigue	3	Right	1.7936	0.001633
15	Female	Pre-Fatigue	3	Left	2.0254	0.001887
15	Female	Post-Fatigue	1	Right	2.2521	0.002014
15	Female	Post-Fatigue	1	Left	2.4088	0.002205
15	Female	Post-Fatigue	2	Right	1.4792	0.001498
15	Female	Post-Fatigue	2	Left	1.4887	0.001623
15	Female	Post-Fatigue	3	Right	1.3808	0.000318
15	Female	Post-Fatigue	3	Left	1.4177	0.000345
16	Male	Pre-Fatigue	1	Right	2.1100	0.001782
16	Male	Pre-Fatigue	1	Left	3.0484	0.002472
16	Male	Pre-Fatigue	2	Right	0.9856	0.000996
16	Male	Pre-Fatigue	2	Left	1.4867	0.001350
16	Male	Pre-Fatigue	3	Right	1.0178	0.000983
16	Male	Pre-Fatigue	3	Left	0.9344	0.000994
16	Male	Post-Fatigue	1	Right	0.6699	0.000948
16	Male	Post-Fatigue	1	Left	0.7719	0.001061
16	Male	Post-Fatigue	2	Right	0.6938	0.000040
16	Male	Post-Fatigue	2	Left	0.7079	0.000041
16	Male	Post-Fatigue	3	Right	0.6972	0.000961
16	Male	Post-Fatigue	3	Left	0.7089	0.000956
17	Female	Pre-Fatigue	1	Right	3.6717	0.002858
17	Female	Pre-Fatigue	1	Left	4.4374	0.004340
17	Female	Pre-Fatigue	2	Right	2.6182	0.002226
17	Female	Pre-Fatigue	2	Left	4.8724	0.003327
17	Female	Pre-Fatigue	3	Right	6.0169	0.004766
17	Female	Pre-Fatigue	3	Left	4.4071	0.003468
17	Female	Post-Fatigue	1	Right	3.2827	0.003163
17	Female	Post-Fatigue	1	Left	3.3989	0.003201
17	Female	Post-Fatigue	2	Right	3.7664	0.003019
17	Female	Post-Fatigue	2	Left	3.4890	0.002149
17	Female	Post-Fatigue	3	Right	3.7142	0.003472
17	Female	Post-Fatigue	3	Left	3.4252	0.003637

Subject	Gender	Status	Trial	Side	RA	RG
18	Male	Pre-Fatigue	1	Right	1.7242	0.001764
18	Male	Pre-Fatigue	1	Left	1.2376	0.001420
18	Male	Pre-Fatigue	2	Right	1.5472	0.001510
18	Male	Pre-Fatigue	2	Left	0.8624	0.000988
18	Male	Pre-Fatigue	3	Right	1.8598	0.002023
18	Male	Pre-Fatigue	3	Left	1.0841	0.001384
18	Male	Post-Fatigue	1	Right	2.6702	0.002798
18	Male	Post-Fatigue	1	Left	1.9109	0.002044
18	Male	Post-Fatigue	2	Right	3.4622	0.002044
18	Male	Post-Fatigue	2	Left	1.7686	0.001224
18	Male	Post-Fatigue	3	Right	2.6383	0.002395
18	Male	Post-Fatigue	3	Left	1.5009	0.001616
19	Female	Pre-Fatigue	1	Right	1.8918	0.001855
19	Female	Pre-Fatigue	1	Left	2.1919	0.002064
19	Female	Pre-Fatigue	2	Right	2.3728	0.002074
19	Female	Pre-Fatigue	2	Left	2.6576	0.002354
19	Female	Pre-Fatigue	3	Right	1.8655	0.001808
19	Female	Pre-Fatigue	3	Left	2.0606	0.001936
19	Female	Post-Fatigue	1	Right	2.8405	0.002382
19	Female	Post-Fatigue	1	Left	2.8369	0.002460
19	Female	Post-Fatigue	2	Right	2.6588	0.002653
19	Female	Post-Fatigue	2	Left	3.6807	0.003450
19	Female	Post-Fatigue	3	Right	1.6448	0.001703
19	Female	Post-Fatigue	3	Left	1.6300	0.002660
20	Male	Pre-Fatigue	1	Right	3.0618	0.002803
20	Male	Pre-Fatigue	1	Left	2.7503	0.002293
20	Male	Pre-Fatigue	2	Right	2.9710	0.002839
20	Male	Pre-Fatigue	2	Left	3.5571	0.003487
20	Male	Pre-Fatigue	3	Right	1.9722	0.002241
20	Male	Pre-Fatigue	3	Left	2.0753	0.001971
20	Male	Post-Fatigue	1	Right	1.6447	0.001180
20	Male	Post-Fatigue	1	Left	1.5411	0.001365
20	Male	Post-Fatigue	2	Right	0.9207	0.001904
20	Male	Post-Fatigue	2	Left	1.7920	0.001819
20	Male	Post-Fatigue	3	Right	1.5569	0.002702
20	Male	Post-Fatigue	3	Left	2.2773	0.001931