

**Upper Trapezius Recruitment with a Repetitive Upper Limb Task:
Comparison of Female WADII Subgroups and Healthy Controls**

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Abstract

Persistent neck pain in whiplash associated disorders (WAD) is a worldwide problem. In an effort to improve classification and management of people with WADII, surface EMG of upper trapezius of the dominant limb was compared between 10 healthy women and 19 women with persistent neck pain post motor vehicle accident, before, during, and after a repetitive upper limb task. Separate analyses were also performed with the WADII women grouped by level of disability (Neck Disability Index scores) as well as using a clinically focused system, the Sterling Classification System (WADIIA, WADIIB, WADIIC). Evidence of abnormalities of upper trapezius recruitment were present in the women with persistent neck pain and WADII, however, further research is indicated to understand the clinical implications of these changes and optimal intervention strategies.

Keywords: chronic pain; surface electromyography; fatigue; EMG amplitude; median frequency; NDI

Dedication

This thesis is dedicated to people with whiplash associated disorders who, despite their best efforts, suffer persistent pain and disability. It is also dedicated to those who seek to improve rehabilitation outcomes for people with whiplash associated disorders, through the pursuit and/or application of new scientific knowledge.

My patient and supportive family and friends have always encouraged me to think big, to do my best, follow my heart and face challenge with enthusiasm and resolve. Their support gave me the courage to initiate this endeavour and the determination and tenacity to realize my goals.

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Thank you to the volunteers who contributed their time to the study in the hopes that future people with whiplash associated neck pain could avoid the prolonged pain, suffering and frustration they had experienced. Thanks are also owed to the numerous clinic owners and staff who supported the study by donating space in their physiotherapy clinics, and the family physicians who took time from their busy schedules to review study documents and sign medical releases allowing volunteers to participate.

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Table of Contents

Approval	ii
Abstract	iii
Dedication	iv
Acknowledgements	v
Table of Contents	vi
List of Figures	viii
List of Tables	ix
List of Abbreviations	x
1. Rationale and Aims	1
1.1 Rationale	1
1.2 Aims	1
2. Literature Review	2
2.1 Subclassification of Patients Post-Whiplash	2
2.2 Chronicity of Whiplash Associated Neck Disorders	4
2.3 Upper Trapezius Recruitment with Westgaard Task	5
2.4 Recruitment of Cervical Flexors with the Westgaard Task	9
3. Research Questions and Hypotheses	10
4. Methodology	12
4.1 Overview of Methodology	12
4.2 Recruitment	14
4.3 Inclusion Criteria	14
4.4 Exclusion Criteria	15
4.5 Clinical Criteria for Modified Sterling Classification	16
4.6 Equipment and Materials	17
4.7 Data Collection Procedures	21
4.7.1 Consent, Demographics and Skin Fold Thickness Measurement	21
4.7.2 Electromyography (EMG) and Pulse Recording	22
4.7.3 Clinical Assessment Rationale and Procedures	27
4.8 Data Processing and Analysis	33
4.8.1 EMG Data Processing	33
4.8.2 Clinical Classification	35
4.8.3 EMG Data Analysis	35
5. Results	38
5.1 Recruitment and Enrolment	38
5.2 Overall Demographics of Participants	40
5.2.1 Demographics of WAD Participants	40
5.3 Classification of WAD Participants	41
5.4 EMG	42
5.4.1 EMG Signal Processing	42
5.4.2 EMG Statistical Analysis Overview	43
5.4.3 Research Question 1: WADII versus Healthy	44
5.4.4 Research Question 2a: Classification by Neck Disability Index Score	51
5.4.5 Research Question 2b: Sterling Classification	56
6. Discussion	61

6.1 Research Question 1: WADII versus Healthy	61
6.2 Research Question 2a: Classification by Neck Disability Index Score	63
6.3 Research Question 2b: Sterling Classification.....	66
6.4 Subclassification of WADII Summary	66
6.5 Underlying Mechanism for Observed Differences in Upper Trapezius Recruitment.....	67
6.6 Limitations	70
6.7 Directions for Future Research	72
7. Appendices.....	75
Appendix 7.1 Summary of Excluded Participants (Healthy and WAD)	75
Appendix 7.2 WADIIA, B, C Criteria as per Sterling 2004	76
Appendix 7.3 Power Analysis.....	77
Appendix 7.4 Regression Formulas for Decision Making Regarding Impaired Cervical Active Mobility	79
Appendix 7.5 Questionnaires.....	80
Appendix 7.5.1 Participants with Neck Pain (Demographics, Work and Health).....	80
Appendix 7.5.2 Neck Disability Index	87
Appendix 7.5.3 Impact of Events Scale (IES)	89
Appendix 7.5.4 Tampa Scale of Kinesiphobia (TSK)	90
Appendix 7.6 WAD Participant Demographics.....	91
8. References.....	101

List of Figures

FIGURE 1	OVERVIEW OF METHODOLOGY	13
FIGURE 2	CROM DEVICE	21
FIGURE 3	UPPER TRAPEZIUS ELECTRODE PLACEMENT	24
FIGURE 4	NON-DOMINANT GASTROCNEMIUS ELECTRODE PLACEMENT.....	25
FIGURE 5	SUMMARY OF SUBJECT RECRUITMENT AND SCREENING	39
FIGURE 6	WADII VS. HEALTHY DUTA MEAN EMG AMPLITUDE (GROUP BY TRIAL)	46
FIGURE 7	WADII VS. HEALTHY DUTP MEDIAN FREQUENCY TRIAL 1 (GROUP BY TIME IN TRIAL)	48
FIGURE 8	WADII VS. HEALTHY DUTP MEDIAN FREQUENCY TRIAL 2 (GROUP BY TIME IN TRIAL)	49
FIGURE 9	WADII VS. HEALTHY DUTP MEDIAN FREQUENCY TRIAL 3 (GROUP BY TIME IN TRIAL)	50
FIGURE 10	NDI CLASSIFICATION DUTP MEAN EMG AMPLITUDE (GROUP BY TRIAL)	55

List of Tables

TABLE 1	VALUES FOR HEAT PAIN THRESHOLDS FOR WAD AT 6 MONTHS POST-INJURY AND CONTROLS IN DEG. C	31
TABLE 2	VALUES FOR COLD PAIN THRESHOLDS FOR WAD AT 6 MONTHS POST-INJURY AND CONTROLS IN DEG. C	31
TABLE 3	STATISTICAL ANALYSES FOR UPPER TRAPEZIUS EMG OF DOMINANT LIMB; DV = DEPENDENT VARIABLE; AMP = AMPLITUDE, DUTP = DOMINANT UPPER TRAPEZIUS POSTERIOR; DUTA = DOMINANT UPPER TRAPEZIUS ANTERIOR.....	37
TABLE 4	DISTRIBUTION OF PARTICIPANTS WITH NDI AND STERLING CLASSIFICATION; TSK = TAMPA SCALE OF KINESIPHOBIA	42
TABLE 5	DUTA 95% CONFIDENCE INTERVALS FOR MEAN EMG AMPLITUDE (% RVE)	46
TABLE 6	SUMMARY OF DEMOGRAPHICS BY NDI GROUP	52
TABLE 7	SUMMARY OF DEMOGRAPHICS BY STERLING GROUP.....	58
TABLE 8	DUTP PERCENTAGE CHANGE IN EMG AMPLITUDE (AMP) AND MEDIAN FREQUENCY (FREQ) RELATIVE TO FIRST HALF OF TRIAL	63
TABLE 9	DUTP PERCENTAGE CHANGE IN EMG AMPLITUDE (AMP) AND MEDIAN FREQUENCY (FREQ) RELATIVE TO FIRST HALF OF TRIAL (NDI GROUPS).....	65
TABLE 10	SUMMARY OF REASONS FOR EXCLUSIONS OF HEALTHY VOLUNTEERS	75
TABLE 11	SUMMARY OF REASONS FOR EXCLUSION OF WAD VOLUNTEERS	75
TABLE 12	SUMMARY OF WADIIA, B, C CRITERIA AS PROPOSED BY STERLING IN 2004	76
TABLE 13	COMPARISON OF VALUES USED IN POWER ANALYSIS VERSUS VALUES REPORTED BY NEDERHAND ET AL 2000.....	77
TABLE 14	REGRESSION FORMULAS AND VARIABLES TO DETERMINE LOWER BOUND OF 95% CI FOR FEMALE NORMS ($Y = A + B * AGE$).....	79

List of Abbreviations

AC: Alternating Current

Ag/Cl: Silver chloride

BNC: Bayonet-Neil-Concelman; A specific type of radiofrequency cable connector named after its bayonet mount locking mechanism and its two inventors, Paul Neill, inventor of the N connector and Carl Concelman, inventor of the C connector

BMI: Body Mass Index; ratio of weight in kg to the square of a person's height in m

BPTT: Brachial Plexus Tension Test; clinical test used to assess mechanosensitivity of brachial plexus, specifically the median nerve to stretch

CCFT: Cranio-cervical Flexion Test; a clinical test used to assess recruitment and endurance of the deep cervical flexor muscles

CROM: Cervical Range of Motion; device used to measure cervical mobility

CT: Computerized Tomography; imaging technique which permits detailed digital two-dimensional views of bony and soft tissue by taking serial x-rays from multiple angles

DC: Direct Current

DGI: Dominant Gastrocnemius Inferior; EMG recording site used in thesis

DGS: Dominant Gastrocnemius Superior; EMG recording site used in thesis

DUTA: Dominant Upper Trapezius Anterior; EMG recording site used in thesis

DUTP: Dominant Upper Trapezius Posterior; EMG recording site used in thesis

EMG: Electromyography; tool for measurement of muscle electrical activity

GHQ-28: General Health Questionnaire-28; 28 item self-report questionnaire developed to screen for recent change in non-psychotic psychiatric conditions which are likely to benefit from intervention from a mental health professional

HC: Healthy controls

Hg: Mercury

IES: Impact of Events Scale; 15 item measure of post-traumatic stress, specifically stress related to a traumatic event (sample available in Appendix 7.5.3)

IIR: Infinite Impulse Response; IIR filters have an “impulse response function that is non-zero over an infinite length of time” (www.wikipedia.org)

MVA: motor vehicle accident

MRI: Magnetic Resonance Imaging; imaging technique which uses a powerful electromagnet and pulsed radio-frequency fields to create detailed two and three dimensional digital images of bony and soft tissue

MVC: maximum voluntary contraction

NDI: Neck Disability Index; 10 item self-report questionnaire measuring neck pain related disability (sample available in Appendix 7.5.2)

NDGI: Non-dominant Gastrocnemius Inferior; EMG recording site used in thesis

NDGS: Non-dominant Gastrocnemius Superior; EMG recording site used in thesis

NDUTA: Non-dominant Upper Trapezius Anterior; EMG recording site used in thesis

NDUTP: Non-dominant Upper Trapezius Posterior; EMG recording site used in thesis

PPT: Pressure pain threshold

ROM: Range of motion

RVE: Reference voluntary electrical; EMG term referring to amount of electrical activity measured during a voluntary reference contraction

SFU: Simon Fraser University

TSK: Tampa Scale of Kinesiphobia; 17 item self report questionnaire designed to measure pathological fear of movement/reinjury (sample available in Appendix 7.5.4)

Vit: Vitamin

WAD: Whiplash Associated Disorder

WAD0: Whiplash Associated Disorders 0; exposure to whiplash mechanism of injury with no signs or symptoms of injury

WADI: Whiplash Associated Disorders I; symptoms of injury following whiplash mechanism of injury, in the absence of objective clinical signs

WADII: Whiplash Associated Disorders II; evidence of injury but no nerve conduction loss on clinical tests and no fracture or dislocation, following exposure to whiplash mechanism of injury

WADIII: Whiplash Associated Disorders III; injury and clinical evidence of nerve conduction loss, following exposure to whiplash mechanism of injury

WADIV: Whiplash Associated Disorders IV; whiplash associated cervical fracture or dislocation

1. Rationale and Aims

1.1 Rationale

Improved understanding of upper trapezius motor control impairments post-whiplash should aid in improved assessment and intervention of some individuals with whiplash associated neck injuries, reducing and/or preventing chronic pain and disability.

Interpretation of previously published research in this area has been hampered by inconsistent findings, differing protocols and inconsistent normalization methods. The aim of the research is outlined below.

1.2 Aims

The aims were to determine if there were significant between-group differences in dominant limb upper trapezius recruitment (mean amplitude and median frequency) pre-task, post-task, during a repetitive upper limb task as well as pre to post-task in adult females with persistent whiplash associated neck disorders (WADII) and healthy female controls, as well as determine if there were differences between subgroups of females with WADII and healthy controls.

2. Literature Review

2.1 Subclassification of Patients Post-Whiplash

Whiplash associated neck disorders are very common in both developed and developing countries. [1-8] In British Columbia alone, approximately 60,000 motor vehicle accident related whiplash associated neck injuries occur per year. [9,10]

In 1995, the Québec Task Force on Whiplash Associated Disorders¹ defined whiplash as “an acceleration-deceleration mechanism of energy transfer to the neck” and proposed the WAD 0-IV classification system for whiplash associated neck disorders. [5] WADII was defined as symptoms and associated signs of neck injury in the absence of clinical evidence of nerve conduction loss (WADIII) or fracture/dislocation (WADIV), following a whiplash mechanism of injury. WAD0 was defined as absence of symptoms and signs of injury, following exposure to an acceleration-deceleration mechanism of energy transfer to the neck (whiplash event) and WADI was defined as symptoms, but no objective clinical signs of injury following a whiplash event.

Although the Québec Task Force Classification system of WAD 0-IV has been adopted worldwide, a mounting body of research suggests that WADII is a heterogeneous group and further subclassification would be of assistance to clinicians and researchers. [2,4,11-21]

¹ The Québec Task Force on Whiplash Associated Disorders was commissioned in 1990 by the provincial automobile insurer of Québec to perform a comprehensive literature review and make recommendations regarding best evidence in the areas of epidemiology, injury mechanisms, prevention, clinical definitions, syndromes and natural history, treatment effectiveness, role of psychosocial factors and impact of service delivery systems in the field of whiplash disorders. It was an independent international, interdisciplinary task force comprised of 25 scientists and clinicians, which evaluated and synthesized whiplash literature to September 1994, and provided supplementary findings from a historical cohort study which evaluated Québec claims data for 1987. In general, they determined there was a paucity of high quality research in this field, with only 62/294 studies being considered both relevant and of sufficient scientific merit. [5]

Upper trapezius has been a subject of study because whiplash injured patients, including people with chronic complaints, frequently complain of tension, pain and fatigue in the region of upper trapezius related to their injury. [5,22-24] Pain in the area of upper trapezius, post-whiplash could potentially be referred from a number of other injured anatomical sources in the mid to lower cervical spine area, including zygapophyseal joint capsule, periosteum or bone, posterior cervical ligaments, intervertebral discs, neural tissue such as the dorsal root ganglia or cervical nerve roots, deeper posterior cervical muscles or the fascia which envelops all of these tissues. [25,26] However, in a review of potential anatomical and physiological sources of persistent pain post whiplash, Siegmund et al noted that the posterior cervical muscles were active and elongated during the flexion moment imposed by simulated rear-end vehicle impacts and that peak muscle fascicle strains were sufficient to cause muscle injury even with an impact velocity of only 8 km/h. A simple muscle strain, depending on the severity, would be expected to resolve within 2-3 months, yet pain and disability frequently persist well beyond that time frame. [1,12,27-29] The same authors, Siegmund et al, also noted, that as of early 2009, it was unknown whether previous findings with respect to alterations in upper trapezius recruitment patterns in WAD were the result of direct injury to the muscle, a response to pain and or injury in other cervical tissues or a combination of the two. A review of findings with respect to altered upper trapezius motor recruitment post whiplash can be found in Section 2.3.

Neck Disability Index Scores (NDI) [30,31] have been used to compare whiplash subgroups regarding other impairments post-whiplash, however, only one study, with two publications, has used NDI subgroups to compare upper trapezius dysfunction post-

whiplash, and the results were inconclusive. [2,28] A more clinically focused system of subgrouping WAD patients was proposed by Sterling in 2004. [32] It was based on differences in motor, sensory and psychological impairments in WADII patients post-whiplash.² To date, upper trapezius recruitment has not been evaluated using the Sterling Classification system.

2.2 Chronicity of Whiplash Associated Neck Disorders

The Québec Task Force on Whiplash Associated Disorders defined the term chronic as symptoms or signs, and or disability, persisting for six months or more post-accident. [5] Currently 30-60 percent of people with whiplash associated neck disorders are still recovering at 6 months or left with apparently permanent disability. [1,12,18,28] Although the prognosis has varied greatly among studies, a systematic review on the topic (The Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders) reported that approximately 50 percent are still symptomatic at one year post-injury. [29] Understanding of relevant motor impairments and their mechanisms post-whiplash should further aid clinicians in applying appropriate treatment(s), thus preventing chronic pain and disability. [2,4,5,14,32-34] Interventions with the strongest evidence base for WADII are: education, joint mobilization and exercise (motor control, endurance, strength, mobility, and relaxation), medication, and psychological management techniques. [2,4,14,32,35-40]

² See Appendix 7.2 for original classification as proposed by Sterling in 2004. [32] See Section 4.5 for description of criteria for WADIIA, WADIIB, WADIIC used in the thesis.

2.3 Upper Trapezius Recruitment with Westgaard Task

Muscle reactivity was defined by Nederhand et al in 2000 as mean surface EMG amplitude post-task minus pre-task (μV or % Reference Voluntary Electrical Activation). [22] The task selected by Nederhand et al for their 2000 study of upper trapezius activity in whiplash injured subjects, was a seated, low load, unilateral repetitive upper limb task which required participants to mark three target circles, arranged in a triangle on a table, at a rate of 88 beats per minute. This task was first described by Westgaard and Bjørkland in 1987 and was termed the Westgaard Task for the purpose of this thesis. [41] The non-dominant arm rested on the table while the dominant limb performed the task. The task was also used in three subsequent studies of upper trapezius activity post-whiplash, and was the task selected for this research. [28,42,43]

In three of the four studies isometric shoulder abduction was used as a reference contraction to normalize EMG amplitude. [22,43,44] The same three studies also compared whiplash injured patients with healthy controls during the task. [22,43,44]

The studies examining upper trapezius activation with the Westgaard Task, using surface EMG, have found conflicting results. [22,28,43,44]

Protocols in the four studies differed in key ways and only one of the studies, Nederhand et al 2003, [28] compared subgroups of a WADII sample (using 6 month NDI scores). [22,43,44] Proposed mechanisms for impaired muscle activation post-whiplash include altered input from injured cervical tissues [17,19,27,45-48], altered proprioception due to pain or inflammatory mediators [19,45], particularly, in the presence of peripheral or central sensitization [46], segmental facilitation or inhibition of alpha motoneurons due to pain [17,27,46], inhibition related to fear of movement/fear of

pain [2,28,46], local muscle injury [17], and or muscle pain [49], altered postural control associated with muscle fatigue [17,45], and altered supraspinal facilitation or inhibition of motor cortex and or alpha motor neurons due to pain [46,50] and or anxiety. [17,46-48,50] Nederhand et al in 2000 reported a significant bilateral difference in muscle reactivity (% RVE) between 16 chronic WADII subjects and 18 healthy controls measuring for one 10 s epoch during one minute of standing pre and post-task (task performed for 2.5 min). [22] Specifically, the WADII subjects had increased muscle activity in upper trapezius post-task compared with pre-task, relative to 18 healthy controls as follows:

- a. dynamic limb 95% CI post-task-pre-task_{WADII} = $9.4 \pm 4\%$ RVE, 95% CI post-task-pre-task_{healthy} = $0.5 \pm 2.5\%$ RVE, p values not reported
- b. stationary limb 95% CI _{WADII}post-task-pre-task = $12.3 \pm 4.9\%$ RVE, 95% CI post-task-pre-task_{healthy} = $0.2 \pm 2.6\%$ RVE, p values not reported.

This was the only study in which 95% confidence intervals did not overlap between groups. [22,28,43,44] Nederhand et al in 2000 also reported a non-significant trend towards increased upper trapezius EMG amplitude in the whiplash injured subjects compared with healthy controls, during the repetitive task, particularly with the stationary limb, measured for 10 s epochs at 10, 60 and 120 s. There were large inter-individual differences in both groups and consequently, 95% confidence intervals overlapped substantially during the task. [22] Other key protocol differences in subsequent studies included EMG measurement pre and post-task in sitting, and using different time parameters for averaging, which likely impacted their findings. [22,28,43,44]

In Nederhand et al 2002, a significant difference in muscle reactivity in 19 chronic WADII subjects versus 18 healthy controls, ($p < 0.01$) was found on the dynamic side only. [43] In the study, four 10 s epochs pre-task and six 10 s epochs post-task, one minute apart, were used for averaging EMG amplitude. In contrast, the time parameters used for analysis in the other three studies were: one 10 s epoch during 1 min of standing pre and post [22], ten 10 s epochs pre and post-task, one minute apart, in sitting [28], and the peak 1 s of one 5 s epoch post-task minus the peak 1 s of one 5 s epoch pre-task, in sitting. [44] Nederhand et al chose not to measure EMG during the task in their 2002 and 2003 studies due to the high within group variability found in their 2000 study. [22,28,43]

In the only study which plotted pre and post-task values, the values were unstable and trends appeared to differ between groups. [43] The authors did not assess for this interaction and did not plot standard deviations or standard errors, limiting interpretation of their findings.

Nederhand et al in 2003, with no control group and no reference contraction, reported no main effect of group when the means of muscle reactivity for five time points from weeks 1-24 post-MVA were averaged for 92 WADII patients grouped by 6 month Neck Disability Index (NDI) scores. [28] Falla et al reported in 2004, that 10 chronic WADII patients demonstrated significantly higher post-task minus pre-task EMG amplitude bilaterally in upper trapezius relative to 10 healthy controls (peak 1 s of one 5 s epoch post-task minus the peak 1 s of one 5 s epoch pre-task). [44] In contrast with Nederhand et al in 2000, Falla et found statistically significant reduced dynamic limb upper trapezius EMG activity during the task (measured for 5 s at 10, 60 and 120 s), in the WAD group

relative to healthy controls, which varied inversely with NDI scores. They also reported low variability of amplitude in the WAD group. Due to the substantial variability of this measure in the control group there was large overlap in 95% confidence intervals. In agreement with Nederhand et al in 2000 they noted significantly higher EMG amplitude in upper trapezius of WAD patients and atraumatic neck pain patients relative to controls in the stationary limb during the task. [22,44]

Although body fat is known to correlate negatively with EMG amplitude [51,52], and De La Barrera noted an inverse relationship between surface EMG frequency and skin fold thickness over biceps; in the two articles (same sample) which reported non-normalized EMG values, BMI was significantly higher in the higher disability group, with no adjustment to the analysis or results. [2,28]

Examining changes in EMG amplitude with changes in frequency should give more complete information but has not been previously studied in whiplash patients using low load tasks. [17,53-56] Both frequency and amplitude are indicative of numbers and type of motor units recruited by the central nervous system, as well as rate coding (increased discharge frequency of motor units with increased load). For example, increased EMG amplitude concomitant with frequency, is indicative of increasing recruitment of additional larger, faster motor units, while increased amplitude accompanied by reduced frequency classically signifies increased synchronization of slow motor units and dropping out of fast motor units associated with fatigue, as well as reduced conduction velocity of previously recruited motor units. [17,57] Unfortunately, with low load tasks the frequency, amplitude relationship in fatigue states has been less predictable. [36,54]

2.4 Recruitment of Cervical Flexors with the Westgaard Task

Falla et al previously reported a significant increase in sternocleidomastoid and scalenus anterior activity both during and after the Westgaard Task in atraumatic neck pain patients, and people with WADII. [44] The findings of increased recruitment of superficial neck flexors in performing both the supine craniocervical flexion test and repetitive upper limb tasks, in people with atraumatic and traumatic neck pain relative to controls, has been a consistent finding, and a positive association with NDI scores has also been noted. [42,44,58-61]

3. Research Questions and Hypotheses

The research questions posed in this study are presented below.

1. Do female³ WADII patients, with persistent neck pain post motor vehicle accident, differ from female healthy controls with respect to dominant upper trapezius surface EMG amplitude and frequency, measured pre, post and during a repetitive upper limb task (Westgaard Task), performed by the dominant limb?

Hypotheses:

a. Differences between the WADII group and healthy controls will be present from both recording sites of upper trapezius of the dominant upper limb during a repetitive upper limb task

b. The WADII group will have difficulty relaxing the upper trapezius to pre-task levels during the post-task standing trial, i.e. higher post-task versus pre- task mean EMG amplitude

c. Differences will exist with respect to time course of median frequency and EMG amplitude within trials and between WADII and healthy controls

2. Do subgroups of female WADII patients, with persistent neck pain post motor vehicle accident, differ from each other and female healthy controls with respect to dominant upper trapezius surface EMG amplitude and frequency, measured pre, post and during a repetitive upper limb task when classified by:

a. NDI scores in to mild to moderate, 10-28, and moderate to severe disability, ≥ 30 or

³ Although Blangsted et al reported no significant gender differences in upper trapezius amplitude during low load computer work in 22 asymptomatic office workers, the values were referenced to maximal isometric shoulder abduction (MVC). [103] The thesis study was too small to assess effects of gender. Given the higher proportion of female chronic WAD patients [2,5,13,104], and the possibility that males and females demonstrate differing recruitment strategies in healthy and pain states, only females were included in this study.

b. sub-grouping as per a modified Sterling clinical classification system (WADIIA, WADIIB, WADIIC)⁴? [32]

Hypotheses:

- a. There will be differences in mean NDI scores between WADIIA, IIB and IIC of the Sterling classification
- b. WADII subgrouping by (i) NDI scores and (ii) Sterling classification will influence EMG amplitude and median frequency measures from both recording sites of upper trapezius of the dominant limb during the upper limb task with respect to pre-task, within task, post-task trials and time in task.

⁴ See Appendix 7.2 for details regarding WADII subclassification as proposed by Sterling in 2004 [32]

4. Methodology

4.1 Overview of Methodology

The study took place in the Injury Prevention and Mobility Laboratory and the Motor Behaviour Laboratory in the Department of Biomedical Physiology and Kinesiology at Simon Fraser University (SFU), as well as several clinics in Vancouver and North Vancouver between fall 2008 and fall 2009.

All subjects signed an informed consent document prior to initiation of data collection. All participants filled in a demographic questionnaire followed by having skinfold thickness measured at four sites. The next portion of the study involved application of surface EMG electrodes and a series of trials measuring surface EMG. All procedures are outlined in Figure 1 and described in detail in section 4.7.

Following the surface EMG measurements, the healthy subjects underwent testing of pressure pain thresholds and the whiplash injured participants filled in several clinical questionnaires and underwent a physical examination by a registered physical therapist. The physical examination included sensory testing (light touch, punctate pain, thermal sensitivity, pressure pain thresholds, and median nerve sensitivity to tension), upper body stretch reflexes (tendon tap), myotomal strength testing, the craniocervical flexion test for deep neck flexor recruitment and active cervical mobility. All procedures are described in detail in section 4.7.3.

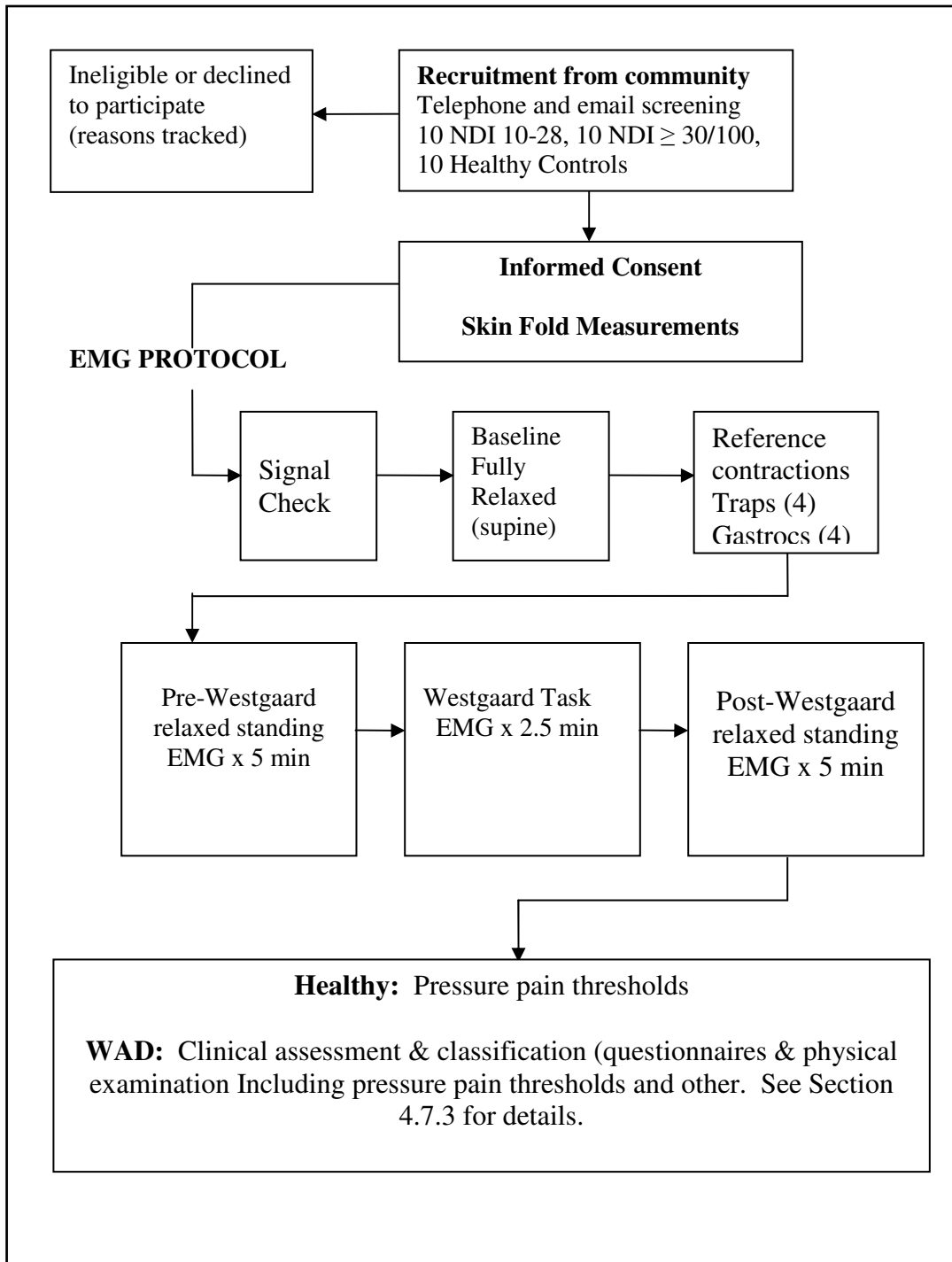


Figure 1 Overview of methodology

4.2 Recruitment

Females with a diagnosis of WADII, and healthy control subjects, were recruited from the community via flyers delivered to offices of family doctors, physiatrists, orthopaedic and sports medicine specialists, licensed allied health care practitioners (physiotherapists, massage therapists, chiropractors and acupuncturists) and private kinesiologists involved with rehabilitation and reconditioning of people post-motor vehicle accident. Emails were circulated and notices were posted at Simon Fraser University, at various public locations, as well as on SFU and community websites, and a paid advertisement was placed on Facebook. All participants were offered the opportunity to have their name entered in a draw to win one of two \$200 prizes.

4.3 Inclusion Criteria

All participants were females, 19-65 years of age. All subjects had to be willing and able to understand and participate in the protocol as described.

A. WADII Eligibility Criteria

The WADII volunteers were included if they reported pain in the neck and or upper thoracic region for a minimum of 6 months post-motor vehicle accident, with onset within 48 h of a motor vehicle accident, and were willing and medically able to discontinue medication likely to affect pain intensity or motor control for 12 hours prior to testing. If eligible, they were required by Simon Fraser University Department of Research Ethics, to provide a medical release form, signed by a medical doctor, confirming it was medically safe for them to participate. The medical release form also confirmed study eligibility.

B. Healthy Controls

The healthy control subjects must have reported an absence of history of neck pain for which they had sought professional treatment.

4.4 Exclusion Criteria

A. WADII

WADII volunteers were excluded if any of the following criteria applied: signs of nerve conduction loss preceding or following MVA, history of cervical fracture or dislocation from MVA (confirmed by x-ray, MRI or CT scan), diagnosed with a concussion related to their motor-vehicle accident or, having a known disorder of their brain or spinal cord which could impact their muscle activation, history of cervical spine surgery, history of widespread pain prior to their trauma (e.g. fibromyalgia), reporting additional causes of neck or upper thoracic pain post-trauma such as osteoporotic fracture or bone infection, a history of neck or upper thoracic pain in the month preceding trauma of sufficient magnitude to seek professional help, or a latex allergy.

B. Healthy Controls

Healthy volunteers were excluded if they were reporting a current neck, upper limb or upper thoracic disorder which was painful or functionally limiting, currently taking any medications which could affect motor control such as pain or sleep medications, or had a known central nervous system disorder which could impact motor control.

A detailed summary of reasons for exclusion for both healthy and WAD volunteers is found in Appendix 7.1

4.5 Clinical Criteria for Modified Sterling Classification

WADII subjects were classified as WADIIA, WADIIB or WADIIC based on the combination of scores on clinical questionnaires and objective findings in the clinical examination. The researcher was blinded to EMG results while performing the clinical examination. The questionnaires are described in Section 4.6 and samples are included in Appendix 7.5. The procedures for the clinical examination are described in detail in Section 4.7.3.

Participants were classified as WADIIA if they did not meet criteria for WADIIB or WADIIC and had any of the following impairments: active cervical mobility measured with the CROM device, which was below the lower bounds of the 95% confidence intervals for gender and age determined using regression formulas provided by Youdas et al in 1992 (regression formulas in Appendix 7.4) [62], inability to maintain 28 mm Hg for 5 s, with relaxed superficial neck flexors and jaw muscles during the supine craniocervical flexion test (CCFT) [61] or mean pressure pain threshold less than 2.3 kg/cm² over the C5/6 articular pillar. [63,64]

Participants were classified as WADIIB if they had any of the impairments outlined for WADIIA and had a score on General health Questionnaire above 23 (Likert scoring 0-1-2-3 for each question). [65]

Participants were classified as WADIIC if they had any of the impairments outlined for groups WADIIA or WADIIB and a score on the Impact of Events Scale (IES) of at least 22 [66] and/or evidence of multimodal sensory sensitization as per Sterling et al 2003. [18] Multimodal sensory sensitization was considered present if two or more of the following criteria were met:

- a. mechanical allodynia, specifically reduced pressure pain thresholds bilaterally at C5/6 (mean < 2.3 kg/cm²) [63,64], over median nerve (mean < 2.0 kg/cm²) [35], and bilaterally over tibialis anterior (mean < 3.1 kg/cm²) [35]
- b. pain reported with non-noxious cool stimulus of 15 deg C applied over any of the two posterior cervical test sites (C5/6 zygapophyseal joints) [13,35]
- c. pain reported with non-noxious warm stimulus of 41 deg C applied over any of the two posterior cervical test sites (bilateral C5/6 zygapophyseal joints) [13,18]
- d) pain of at least 3.5/10 and elbow extension range at pain threshold, of less than or equal to minus 33 degrees with brachial plexus tension test (BPTT; screening for upper limb neural irritability) [18]

The values for the BPTT were chosen based on data from Sterling et al 2003, in which the researchers found that only the group who still had abnormal BPTT and NDI scores greater than 30 at six months, met these criteria at 1 month post-injury. [18] The pain and elbow mobility values during the BPTT had returned to control values by 2 months in the other WAD subgroups.

4.6 Equipment and Materials

Two questionnaires were included to capture demographic information about participants. The healthy volunteers filled in a Healthy Volunteers Demographics questionnaire which was comprised of questions regarding age, height, weight, occupation, and hand dominance. The WAD volunteers filled in the custom Whiplash Injured Volunteers Demographics, Work and Health questionnaire which included questions regarding demographics (age, height, weight, occupation, hand dominance), as well as date of MVA, onset of symptoms post-MVA, current medication for MVA

symptoms and other medications, work status (returned to occupation, working modified hours or duties, off work due to MVA, other), direction of collision (rear impact, side impact, front impact, other), a symptom checklist to determine number of areas affected from MVA as well as a question regarding comorbidities. See Appendix 7.5.1. Slim Guide Skin Fold Calipers were used to measure skin fold thickness.

The Noraxon Myosystem 1200 EMG system was utilized and included Noraxon pregelled dual bipolar Ag/AgCl surface electrodes (2 cm inter-electrode distance, 1 cm diameter), a reference electrode, Noraxon amplifier (DC offset $\sim \pm 60$ mV, AC Base Line < 1.8 mv rms, Common Mode Rejection Ratio > 100 dB, preset gain of 1000, input impedance > 10 MOhm), Noraxon junction box and a Class II medical grade power supply. Other equipment for the EMG portion of the study included a National Instruments data acquisition board, National Instruments data acquisition cards (12 bit with SFU system, 16 bits with off-site system) and a PC. Two data acquisition software programs were used. EVaRT 5.0 was used at SFU, and Labview 8.6 Student Version, with a custom program written by Dr. James Wakeling, and modified by the researcher was used off-site.

A Polar heart rate monitor was connected to the volunteer and a Polar wireless receiver with customized connections and 5V transformer was connected by BNC to the data acquisition board, for collection of pulse data. A 74.5 cm high conventional table was used at SFU for the repetitive upper limb task and an identical height, custom portable table with two legs, was used with adjustable height treatment beds, at non-SFU sites. A standard adjustable height office chair and metronome were also used for the repetitive upper limb task.

Clinical examination tools included tools for screening for WADIII, the Neck Disability Index to determine NDI group [30,31], and tools utilized for assignment of Sterling classification. Tools used to screen for WADIII (clinical evidence of radiculopathy) included a Taylor reflex hammer, cotton balls and a Wartenberg pinwheel. The NDI is a 10 item measure of neck pain related disability which was scored out of 50, then converted to a score out of 100. It included an additional question regarding pain level 0-10. See Appendix 7.5.2.

The questionnaires used to assign a Sterling Classification were the General Health Questionnaire-28 (GHQ-28), and the Impact of Events Scale (IES). The Tampa Scale of Kinesiphobia (TSK) was administered as it was part of the original Sterling Classification proposed in 2004 [32], but was not used to assign a Sterling Classification. The GHQ-28 is a 28 item measure developed to screen for recent change in non-psychotic psychiatric conditions which are likely to benefit from intervention from a mental health professional. [65,67-69] This questionnaire was excluded from Appendix 7.5 due to copyright restrictions. The IES is a 15 item measure of post-traumatic stress, specifically stress related to a traumatic event. [70] This measure was designed to screen for, but not diagnose post-traumatic stress disorder, which can only be reliably diagnosed by a trained mental health care professional. [66,70] It is a reliable and valid screening tool and a copy is provided in Appendix 7.5.3. The TSK is a 17 item test designed to measure pathological fear of movement/reinjury and a copy is provided in Appendix 7.5. 4. [71]

Other clinical tools used to assign a Sterling Classification were a Wagner Instruments FN-100 Pressure Algometer marked in 0.1 kg/cm² increments, two portable thermal testers (USNeurologicals.com), a Hot Spa Professional foot bath Model 61360, a cold

water bath, thermometers marked in 1 degree increments, a manual goniometer marked in 1 degree increments used for the brachial plexus tension test, Chattanooga Stabilizer Pressure Biofeedback Unit and the CROM (cervical mobility tester; Performance Attainment Associates, USA).

The CROM consists of a plastic frame mounted to the bridge of the nose and the ears and secured by a Velcro strap as well as a magnetic yoke which is placed over the shoulders. The plastic frame contains two gravity goniometers for measurement of active mobility in the frontal and sagittal planes respectively, and a compass that operates with the yoke to measure transverse plane mobility (Figure 2). The dials are marked in two degree increments. In a sample of 60 orthopaedic neck pain patients, the intra-rater reliability ranged from 0.84-0.95 and inter-rater reliability ranged from 0.73 to 0.92 (depending on the direction of movement). [72] In two samples, with 84, [72] and 30 healthy subjects each [73], the intra-rater reliability ranged from 0.92-0.96 and 0.88-0.96 respectively. The inter-rater reliability ranged from 0.84-0.92 [72] and 0.75-0.90. [73] The CROM has been found to be superior to other clinical methods of measuring cervical mobility, with respect to reliability, including visual estimation, use of a manual universal goniometer, a single inclinometer, as well as a device similar to the CROM called the Cervical Measurement System. [72-74]

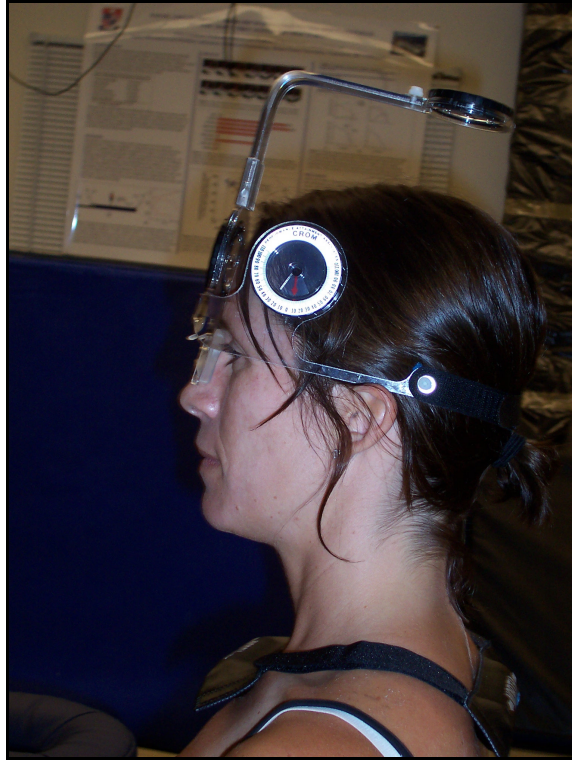


Figure 2 CROM device

4.7 Data Collection Procedures

The participants took part in the procedures described in the order in which they are presented below. Data collection involved measurement of skinfold thickness, EMG evaluation and a clinical assessment.

4.7.1 Consent, Demographics and Skin Fold Thickness Measurement

Informed consent was obtained from each participant and documented prior to initiation of data collection. All participants were then administered a questionnaire in which they were instructed to fill in their age, height, weight, occupation and hand dominance. The participants stood or sat quietly while the researcher used skin fold calipers, to measure skin fold thickness at the midpoints of the front and back of the right arm, below their

right shoulder blade (at the inferior angle of the scapula) and above the right hip/pelvis (just above the iliac crest) as per Nordander et al 2003. [52]

4.7.2 Electromyography (EMG) and Pulse Recording

All subjects were measured for consistency of electrode placement, had their skin prepared for the application of electrodes, followed by attachment of electrodes and securing of leads. Once the heart rate monitor and EMG electrodes were appropriately secured, collection of heart rate and EMG data was initiated. All procedures are described in detail below.

Preparation of Participants for EMG

The participants sat and stood quietly while the researcher prepared their skin and then applied surface electrodes to measure muscle activity (EMG) at several sites. Skin preparation involved cleaning the skin with alcohol as well as vigorous rubbing of the skin, and, sometimes required shaving with a disposable razor, if the area was hairy. These procedures were performed to minimize skin resistance and optimize the signal to noise ratio of the EMG recording.

Two electrodes were applied over each muscle to increase the number of recorded motor units, thereby giving both greater sensitivity to abnormalities and improved context to findings. The result recording from two electrodes in similar locations over the same muscle would be expected to be dependant on the task, muscle and location over the muscle.

The researcher then applied two EMG electrodes to both the dominant and non-dominant upper trapezius muscle. The posterior upper trapezius electrode sites were dominant upper trapezius posterior (DUTP) and non-dominant upper trapezius posterior

(NDUTP) and were located at a point 38 percent of the distance measured from the lateral prominence of the acromion to the C7 spinous process (Figure 3). [75] The anterior upper trapezius electrodes, dominant upper trapezius anterior (DUTA) and non-dominant upper trapezius anterior (NDUTA), were placed immediately ventral to DUTP and NDUTP. Figure 3 depicts electrode placements for upper trapezius. Measurements from two electrodes recording from different anteroposterior locations along the upper trapezius muscle have previously been shown to differ. An electrode placed along the same line as DUTP measured greater changes representative of fatigue during sustained shoulder flexion at 30% MVC, relative to an electrode that was placed more caudally [76] A similar finding was reported from different craniocaudal placements, using 6 intramuscular electrodes, during 30 minutes of continuous use of a computer mouse. [77] Wakeling et al reported that EMG findings recorded from adjacent electrodes placed on rectus femoris, biceps femoris, tibialis anterior and medial gastrocnemius, while the subjects ran continuously for 30 minutes, did not differ. [78]

Gastrocnemius was selected as a reference muscle. It was hypothesized that, differences between the healthy and WADII groups found in upper trapezius, would not be found in gastrocnemius, due to the mechanism of whiplash injuries and the demands of the task, neither of which would be expected to impact this muscle. Two electrodes were applied to each lateral gastrocnemius muscle. Inferior gastrocnemius electrodes were placed on the side of the dominant upper limb (Dominant Gastrocnemius Inferior; DGI) and the side of the non-dominant upper limb (Non-dominant Gastrocnemius Inferior; NDGI), 1/3 of the distance between the proximal tip of the head of the fibula and the Achilles insertion (Figure 4). [79,80] Superior gastrocnemius electrodes, Dominant

Gastrocnemius Superior (DGS) and Non-dominant Gastrocnemius Superior were placed cranial and immediately adjacent to DGI and NDGI electrodes. See Figure 4 for depiction of gastrocnemius electrode placement.

A reference electrode was applied to the left patella. The researcher applied tape to the participant's skin to ensure the leads did not move excessively during data collection.

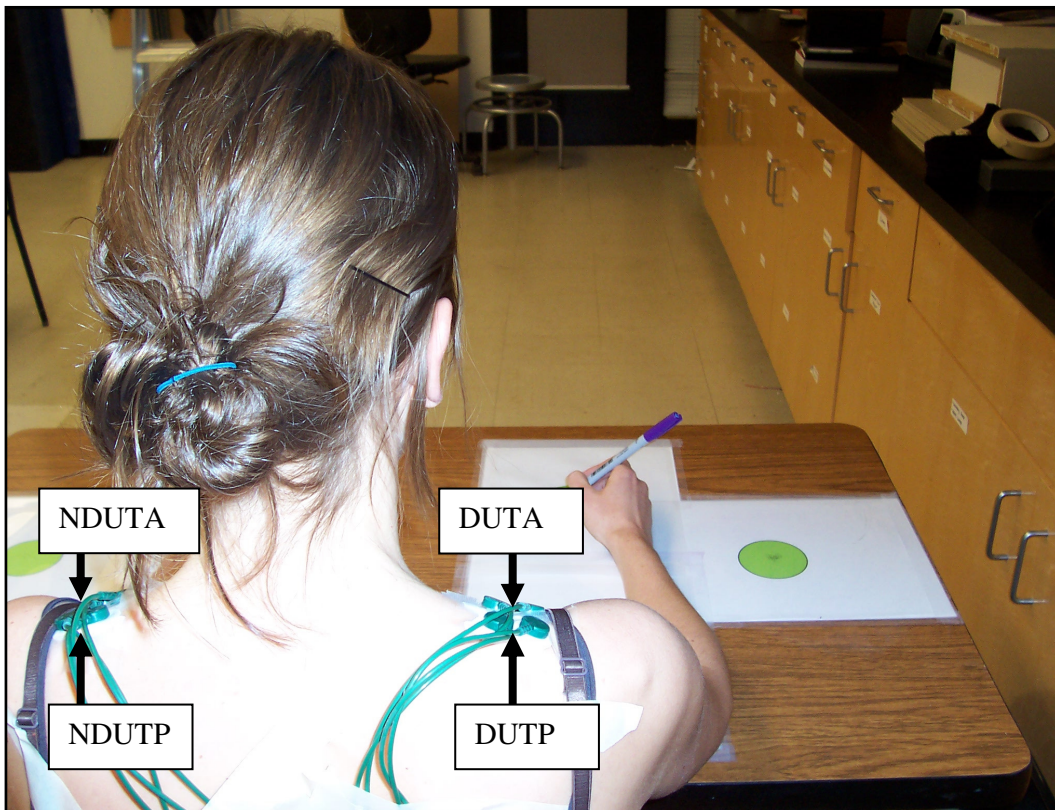


Figure 3 Upper trapezius electrode placement

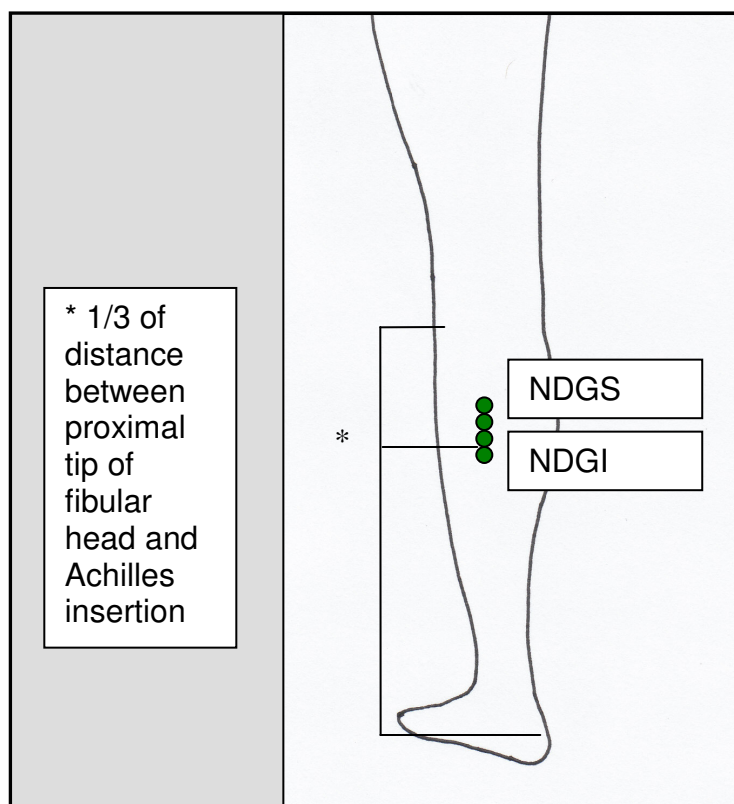


Figure 4 Non-dominant gastrocnemius electrode placement

Pulse Recording

A Polar Heart Rate transmitter was moistened and fastened around the chest of the volunteer. The signal from each heartbeat was recorded by a Polar receiver connected to a custom connector and transmitted to the PC. It was also connected to the main power supply and a 5V transformer. Pulse information was recorded due to visible contamination of the raw EMG signal with cardiac signals in pilot data. It was recorded in case adaptation of data processing or analysis became necessary in order to contend with this potential confounder.

EMG Recording

Noraxon dual electrodes were used which had two, 1 cm diameter Ag/AgCl electrodes, and a set inter-electrode distance of 2 cm. The Noraxon Myosystem 1200 was used,

which has a preset filter that selectively records signals in the range of 10-500 Hz. The sampling rate was 2000 Hz and EMG was recorded continuously for each trial.

There were fifteen trials. An overview of the trial sequence is provided in Figure 1 and this section describes the trials in detail.

The purpose of the first trial was to check the signals, and ensure that the system was recording properly. The participant stood and performed a series of three dynamic bilateral plantarflexion movements followed by three dynamic repetitions of shrugging the shoulders. For one healthy participant, the inferior gastrocnemii electrodes were moved 2 mm medially due to lack of visible signal.

The second trial was a baseline recording. The participant rested in supine on a treatment table, with pillows under head and knees for 4 minutes, followed by EMG recording for 1 minute.

The next eight trials were reference contractions. There was a one minute rest between each reference contraction. When resting in sitting, the participant had back and feet supported and hands resting in their lap, with palms down. The participant performed four trials of seated bilateral shoulder abduction at 90 degrees, with palms facing downwards, maintained for 10 s, for upper trapezius. In the next sequence of four trials the participant maintained standing bilateral plantarflexion for 5 s.

A pre-task recording was performed with the volunteer in quiet standing for 5 minutes. They were instructed to stand with their arms at their sides, feet hip width apart and good posture while looking straight ahead. Volunteers were told when each minute had passed. A one minute rest preceded the repetitive task.

The repetitive upper limb task was performed for 2.5 minutes. The volunteer was seated in an office chair and marked target circles arranged in an equilateral triangle, on the table, at 88 bpm using the dominant limb. The hand and forearm of the non-dominant limb rested on the table. The circles were 70 mm in diameter with centers 23 cm apart. Prior to measurement of skinfold thickness, the chair was adjusted to a height that would allow the participant's feet to rest flat on the floor and their hips to be flexed 90 degrees. Subsequent to adjustment of chair height, participants were asked to practice the task until they demonstrated proficiency (less than 30 s). A post-task recording was performed with the participant in quiet standing for 5 minutes, as per the pre-task standing trial.

The final recording occurred while the participant rested quietly in supine, with pillows under head and knees for 1 minute. The final recording was included to capture clean heart rate data in case adjustments were required in analysis of data before, during, or after the repetitive task.

4.7.3 Clinical Assessment Rationale and Procedures

The clinical assessment served to confirm WADII status [5], to classify volunteers as WADIIA, B or C, and to determine NDI group. [32] This portion of the study included administration of the questionnaires to WADII participants and, healthy volunteers had pressure pain thresholds measured, but did not participate in any other clinical testing. Tests for WAD participants were performed in the order presented below.

Clinical Physical Examination: Screening for WADIII

Tests included for the purpose of screening for WADIII were assessment of upper body light touch and punctate pain sensation, tendon tap reflexes and key muscle strength. Perception of light touch was assessed by the examiner stroking the skin with cotton balls, or index fingers if over clothing, bilaterally, and from medial to lateral across dermatomes. Areas tested include upper thoracic, beginning at T2, upper limbs, neck and head unless otherwise stated. [81-83] A pattern of sensory loss consistent with radiculopathy, constituted a positive test.

A Wartenberg plastic pinwheel was used to assess sensation to punctate pain, at the pads of the thumbs (C6), tips of third digits (C7), tips of fifth digits (C8/T1), 2 cm distal to the lateral margin of the acromion (C5), and 2 cm lateral to the external occipital protuberance (C2/3). [26] Participants were asked to report whether they felt the dull or sharp aspect of the device. A pattern of sensory loss consistent with radiculopathy, constituted a positive test.

Tendon tap (stretch) reflexes were tested using a reflex hammer to apply a stretch to the tendons of biceps, brachioradialis (if bicipital stretch reflex reduced), and triceps, with the volunteer seated in a firm chair with back support, and their arms supported on a pillow to facilitate relaxation. Areflexia or asymmetric hyporeflexia, in conjunction with myotomal weakness at the same segment, consistent with radiculopathy, constituted a positive test.

The researcher tested myotome strength by maximally resisting a series of isometric contractions with the participant seated. The directions tested were 5th digit abduction (T1 > C8), 1st interphalangeal flexion (C8 > C7), elbow extension (C7 > C6, C8), wrist

extension (C6 > C7, C8), elbow flexion (C6 > C5), shoulder external rotation (C5 > C6), scapular elevation (C3-5, accessory nerve), and craniovertebral flexion (C1-3). The nerve root contributions in brackets are listed as per Gray's Anatomy 38th edition. [26] The test was considered positive if isolated, myotomal weakness ($\leq 4/5$ on the Oxford Scale) was present, and strength was not limited by pain. [84]

Clinical Examination: Classification

Procedures used to assign a Sterling Classification, were, administration of questionnaires (IES, GHQ-28), performance of thermal sensitivity tests, the brachial plexus tension test, testing of pressure pain thresholds, the craniocervical flexion test (CCFT), and measurement of active cervical mobility.

Questionnaires administered to the volunteers in this phase were Whiplash Injured Volunteers Demographics, Work and Health questionnaire, the Neck Disability Index, the Tampa Scale of Kinesiphobia, the General Health Questionnaire-28 and the Impact of Events Scale. The Neck Disability Index was administered, in order to determine group assignment by NDI score, NDI_{10-28} or $NDI \geq 30$. The results from the Tampa Scale of Kinesiphobia (TSK) and the Whiplash Injured Volunteers Demographics, Work and Health questionnaire were used for demographic purposes only. The researcher assessed the questionnaires for completeness and prompted the participants to complete any unanswered questions. See section 4.6 for descriptions and Appendices 7.5.1-7.5.4 for copies of the questionnaires.

Thermal sensation was tested to normally non-noxious stimuli using portable hand-held thermal testing devices applied to C5/6, posteriorly, on right and left sides. One thermal tester was maintained at a set temperature of 15 degrees C and the other at 41 degrees C.

There was a 10 s break between each test and warm and cool stimuli were applied in random order, three times each. Warm water was kept heated by use of a heated foot bath device. The temperatures of the cool and warm baths were adjusted as necessary using ice cubes and water heated in a kettle.

As heat and cold pain thresholds in some areas of the body have been shown to vary widely [85], but Sterling et al showed low variability at the posterior aspect of the neck in controls and subgroups of WADII and WADIII patients [18], only the neck served to classify people as WADIIC with respect to presence or absence of thermal allodynia.

These tests were derived from literature by neurologists and their use of the Lindblom roller and other devices with set temperatures, to diagnose people with reduced thermal sensation, and those with thermal hyperalgesia in clinical practice. [81,86] The method was consistent with the 2004 EFNS (European Federation of Neurological Societies) guidelines for clinical neuropathic pain testing. [83] They recommended use of thermal rollers at preset temperatures. Commercial thermal rollers are preset to 25 and 40 degrees; however previous research indicates the 25 degree roller would miss many whiplash injured patients with cold allodynia at the posterior neck. [13,18,35] The temperatures for assessing warm and cold allodynia were derived from data from Sterling et al 2005[13], and Sterling et al 2003. [18] See Tables 1 and 2 for further detail. Additionally, Jull et al used a cut off of 14.6 degrees for female cervical cold pain thresholds in their randomized controlled trial published in 2007, based on previous findings with respect to WAD patients with poor recovery. [35]

Table 1 Values for heat pain thresholds for WAD at 6 months post-injury and controls in deg. C

	Controls	6 month values	6 month values	6 month values
	95% CI	95% CI	95% CI	95% CI
		6 month NDI 0-8	6 month NDI 10-28	6 month NDI 30
Sterling et al 2005 [13]	NA	43.1 ± 1.2 (41.9-44.3)	43.4 ± 1.3 (42.1-44.7)	39.5 ± 1.6 (37.9-41.1)
Sterling et al 2003 [18]	43.2 ± .2	42.6 ± .1	43.1 ± .1	39.5 ± .2 (39.3-39.7)

Table 2 Values for cold pain thresholds for WAD at 6 months post-injury and controls in deg. C

	Controls	6 month values	6 month values	6 month values
	95% CI	95% CI	95% CI	95% CI
		6 month NDI 0-8	6 month NDI 10-28	6 month NDI > 30
Sterling et al 2005[13]	NA	10 ± 1.9 (8-12)	11 ± 2.2 (9-13)	19.9 ± 3 (17-23)
Sterling et al 2003 [18]	9.7 ± 0.6 (9-10)	11.6 ± .4 (11-12)	11.4 ± .4 (11-12)	19.2 ± .7 (19-20)

The brachial plexus tension test [18] was performed with the participant resting in supine with their head and neck supported by a pillow. The examiner sequentially applied gentle unilateral shoulder girdle depression, and then moved the limb into glenohumeral abduction and external rotation in the coronal plane, followed by wrist and finger extension, and elbow extension. The degrees of elbow extension and pain level (Numeric Rating Scale of 0-10), at onset of pain, were evaluated.

Pressure pain thresholds were assessed over the anterior leg, on the most prominent point of the muscle belly of tibialis anterior [63], over the median nerve at the elbow, adjacent to the biceps brachii tendon in cubital fossa [63] and, at the posterior neck, over the C5/6 articular pillar. [63] These sites were selected as they have been found to be representative of pressure hypersensitivity in WAD. They were assessed on the left, followed by right sides, at each site, and three measurements were taken at each site, with a 10 s break between each repetition.

The progressive craniocervical flexion test was performed using a pressure biofeedback unit as described by Jull in 2000. [61] The participant lay supine on a treatment table, and the pressure cuff was folded, placed behind the neck and then inflated to 20 mm Hg. They were asked to place their tongue on the roof of their mouth, keep lips together and teeth slightly apart, to inhibit muscles associated with mandibular depression. [61] Manual pressure was applied to the latex bag to ensure the pressure was evenly distributed and, if the pressure dropped during application of manual pressure then the bag was inflated back to 20 mm Hg to compensate. [61] The volunteer was instructed to slowly and gently nod their head similar to indicating “yes” and hold the position for 5 s, once the researcher indicated verbally that the target pressure had been reached. The task was repeated, if successfully completed, for the target pressures of 22-28 mm Hg, with increments of 2 mm Hg. A 10 s rest was provided between increments. They were able to view the dial in order to obtain visual feedback on their performance and were allowed up to one minute of practice and familiarization with the task to ensure optimal performance and minimize the number of false positives.

Active cervical mobility was assessed using the CROM device (Figure 2). The device was applied to the participant's head and shoulders. The participant was instructed to move as far as possible in each direction until they felt increased pain or increased muscle tension, keeping the shoulders still, followed by a return to the start position (facing directly ahead). Each movement was demonstrated by the researcher and repeated three times by the participant. The mean of the three repetitions was used to determine active mobility for that direction. The order of testing was: flexion, extension left lateral flexion, right lateral flexion, left rotation, right rotation.

4.8 Data Processing and Analysis

The following description is limited to the dominant upper trapezius electrodes (DUTP and DUTA) as results for the non-dominant upper trapezius and gastrocnemius channels were not included in the thesis document.

4.8.1 EMG Data Processing

All EMG data was processed, off-line in MATLABR2007a (student version). Digital filters were applied, baseline levels were subtracted and the data were normalized to the relevant reference value. The details are described below.

Filtering

A 24th order Type 2 Chebyshev IIR bandpass filter in the range 35-500 Hz was applied to EMG data from upper trapezius, to filter out contamination from cardiac signals (high pass filter) as per the recommendations of Drake et al. in 2006 [87], and to filter signals higher than 500 Hz, which were unlikely to be electrical signals from contracting muscle, in accordance with the 1999 European guidelines for surface EMG. [79] Due to the low signal to noise ratio with all recordings, except during the repetitive task, and frequent,

significant 60 Hz spikes evident in the power spectral density plots, a 4th order Type 2 Chebyshev IIR 59-61 Hz notch filter was applied to EMG recordings from both channels. Both filters were designed to optimize filter effectiveness while retaining as much EMG data as possible. The 24th order filter was of a somewhat higher order than conventional filters, however, Zhou et al reported that increasing filter order higher than a 6th order Butterworth filter had no significant impact on EMG data recorded from pectoralis major, but further reduced ECG contamination. [88]

The mean amplitude (rms) for the EMG data was calculated for each trial, using MATLAB. In the analysis of pre-task, during repetitive task and post-task trials, amplitude and median frequency values were calculated for each 10 s block. The window size utilized for calculation was 1 s (2000 data points).

In the case of pre-task, during the repetitive task and post-task, median frequency was calculated using the filtered data. The data were first converted to the frequency domain using the fast Fourier transform for each 10 s block. The data was then converted to a power spectral density plot by taking half of the fast Fourier transform and creating a periodogram (squaring the magnitude of each data point and then multiplying by 2). The median frequency was calculated for each 10 s block by finding the frequency that divided the area of the periodogram in half.

Baseline Subtraction

Baseline subtraction was performed in order to optimize the signal to noise ratios. The root mean square of the baseline EMG amplitude measured in supine for 1 minute was calculated for each participant and each channel. Subtraction of the mean baseline amplitude (root mean square or rms) for each participant and each channel was

performed for the pre-task, during task and post-task trials, and from each channel for the reference contractions. Mean baseline amplitude was expressed in μV . In one subject, the baseline trial was contaminated by electrical interference from an adjustable therapy table, therefore, the data from the 60 s seated trial was utilized instead. Baseline subtraction was performed using Microsoft Office Excel 2003.

Normalization of EMG Amplitude Data

The mean amplitude for the dominant upper trapezius reference contractions was calculated for each channel individually (DUTA and DUTP) by averaging across four contractions. Mean EMG amplitude was expressed in μV for dominant upper trapezius seated bilateral shoulder abduction of 90 degrees (DUTP and DUTA). Excel 2003 was used to reference the mean EMG amplitude values for the pre-task, during repetitive task and post-task trials to the mean reference value (baseline subtracted from each), for each channel.

4.8.2 Clinical Classification

Each whiplash injured participant was classified by both NDI score (mild to moderate 10-28 or high ≥ 30) and Sterling Classification (WADIIA, WADIIB or WADIIC). Demographic information was collated and analyzed using SPSS16.

4.8.3 EMG Data Analysis

Statistical analysis was performed using SPSS16. For the purposes of this thesis, analysis focused on the mean amplitude (percent of reference amplitude or RVE) and median frequency of the filtered data from the anterior and posterior channels of upper trapezius of the dominant limb (DUTP and DUTA). Analysis and results are not reported for the non-dominant upper trapezius channels or the gastrocnemius channels.

Separate analyses were performed for each classification system, for each dependant variable and for each channel of upper trapezius of the dominant limb, as per Table 3. Three series of analyses were performed, using categorization as follows: healthy versus WAD, grouping based on NDI score (healthy, NDI 10-28/100, $NDI \geq 30/100$), and grouping based on modified Sterling Classification (healthy, WADIIA, WADIIB, WADIIC). Mixed ANOVA was performed with mean amplitude and median frequency as dependant variables. In the analysis of time in trial (early, late), standing trial results were averaged across the first and last half of each trial, while the first and last 70 s recorded during the Westgaard Task were compared. Significance was pre-determined to be $\alpha = 0.05$ and Sidak or Games-Howell post hoc tests were selected, as appropriate, to control the family-wise Type I error rate in each analysis. In the case of group interaction effects, independent repeated measures ANOVAs were conducted for each group, followed by descriptive analysis of the differences. Subject numbers of the outliers were determined from box-plots to determine if there were any subjects that were consistent outliers across trials and channels and if any action to adjust for this was indicated.

Table 3 Statistical Analyses for Upper Trapezius EMG of dominant limb; DV = dependent variable; amp = amplitude, DUTP = Dominant Upper Trapezius Posterior; DUTA = Dominant Upper Trapezius Anterior

Analysis	DV1	DV2
1. WAD vs. Healthy	i. EMG amp (referenced)	ii. Median Frequency
Group (2) x Trial (3) x Time in Trial (2)	a. DUTP b. DUTA	a. DUTP b. DUTA
2. NDI (3 groups)	i. EMG amp (referenced)	ii. Median Frequency
Group (3) x Trial (3) x Time in Trial (2)	a. DUTP b. DUTA	a. DUTP b. DUTA
3. Sterling Criteria (4 groups)	i. EMG amp (referenced)	ii. Median Frequency
Group (4) x Trial (3) x Time in Trial (2)	a. DUTP b. DUTA	a. DUTP b. DUTA

5. Results

5.1 Recruitment and Enrolment

One hundred and two enquiries were received from potential volunteers with neck pain and thirty-four were received from potential healthy volunteers (see Figure 3 for a summary of numbers of volunteers at each stage of the recruitment and enrollment process). Five healthy women and nineteen women with neck pain chose not to participate in the study. Following initial screening and exclusion of ineligible volunteers (13 healthy and 54 women with neck pain), all eligible WAD volunteers obtained a signed medical release from their family physician or medical specialist. Twelve healthy and twenty-five WAD volunteers enrolled in the study. Two enrolled WAD volunteers were subsequently excluded due to NDI scores which fell outside the range required for the study and four were excluded due to unilateral sensory and or motor impairments consistent with radiculopathy, classifying them as WADIII. [5,29,89] Ten healthy, nine WADII subjects with NDI scores of 10-28/100 and ten subjects with NDI scores of at least 30/100 were included in data analysis.

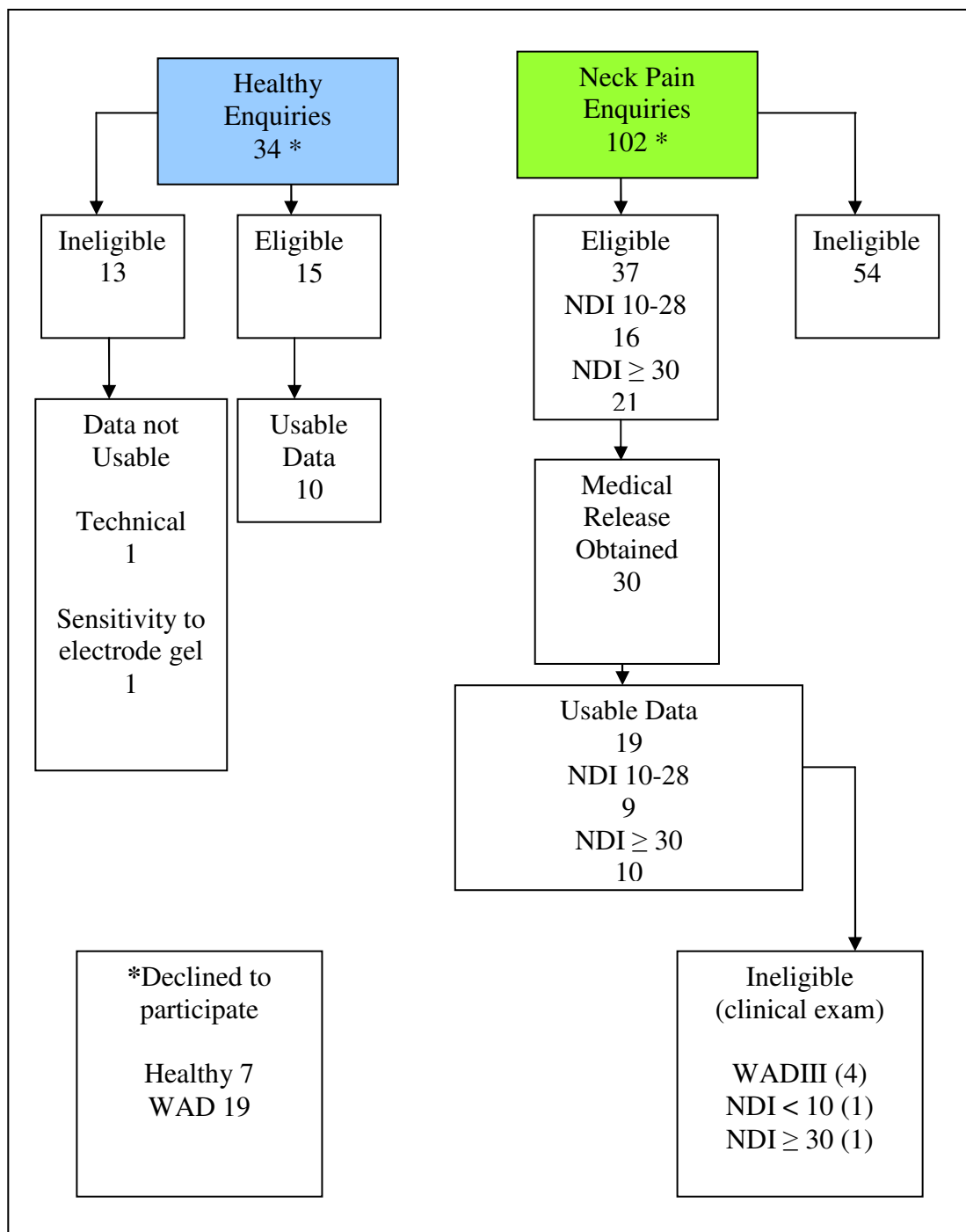


Figure 5 Summary of subject recruitment and screening

5.2 Overall Demographics of Participants

The mean age of the 10 healthy participants was 31.6 years (sd 10.8; range 21-53) which was lower than that of the 19 whiplash injured participants mean of 38.8 (sd 13.2; range 19-58). The difference in mean ages was not statistically significant ($t = -1.488$, $p_{\text{onetailed}} = 0.074$).

5.2.1 Demographics of WAD Participants

In the whiplash-injured group, the mean time since their motor vehicle accident (MVA) was 5.2 y (sd 5.7 y) with length of time post MVA ranging from 0.8-18.5 y. Volunteers were included in the study, only if they reported their neck pain had persisted from the time of the MVA. Fifty-eight per cent of the participants with whiplash injuries were less than 3 years post MVA. The self-reported direction of impact in their collisions was: rear 53%, side 21%, front 16% and other in 11% of cases (1 rear and front and 1 single vehicle accident involving a rollover down an embankment). The mean NDI score, 39/100, represented moderate to severe disability (sd 18), with scores ranging from 16-70/100 and the mean, typical pain reported was moderate (mean = 5, sd 2.3; range 1-8), on a scale of 0-10. Forty-seven per cent of the WADII participants had fully returned to work, 28% had partially returned and 28% reported being unable to return to work as a result of their MVA. Three of the 5 participants who had not returned to work, were on long term disability (one due to an MVA related low back injury), and two were in school to train for alternate occupations. One participant, who reported working full time, also reported they had changed careers due to injuries from their MVA.

Eighty-four per cent of WAD volunteers selected “neck or upper back pain and muscle tension including past week” as their worst upper body or generalized symptom from a

list containing 28 possible selections. All of the participants reported multiple symptoms, with the mean number being 11 (sd 5; range 2-22). Forty-two per cent of WAD participants reported no medication intake, while the rest were taking a variety of medications, including antiinflammatories (53%), analgesics (26%), muscle relaxants (26%) and other (26%). See Appendix 7.6 for details. The details regarding breakdown of group demographics by classification system are described with the results for each of NDI and Sterling analyses.

5.3 Classification of WAD Participants

The 19 WADII participants were classified by NDI score and by Sterling Classification in to WADIIA, WADIIB or WADIIC. All participants classified as WADIIC had NDI scores greater than 30 but there was a wide range of scores for the WADIIA and WADIIB groups. See Table 4 regarding the distribution of participants using the two classification systems.

Table 4 Distribution of participants with NDI and Sterling Classification; TSK = Tampa Scale of Kinesiphobia

CLASSIFICATION	NDI10-28	NDI≥30
WADIIA NDI mean 29.7, sd 14.8 range 16-58 TSK mean 40.1, sd 11.4 range 25-60	4	2
WADIIB NDI mean 38.2, sd 20.1 range 22-70 TSK mean 40.7, sd 8.3 range 29-50	5	3
WADIIC NDI mean 51.6, sd 11.8 range 38-64 TSK mean 44.8 sd 7.9 range 34-55	0	5

5.4 EMG

The focus of this thesis was upper trapezius of the dominant limb. The results for DUTP (Dominant Upper Trapezius Posterior) and DUTA (Dominant Upper Trapezius Anterior) are presented in Section 5.4. The results for upper trapezius of the non-dominant limb and gastrocnemius were not included in the thesis document.

5.4.1 EMG Signal Processing

Following application of digital filters, the mean baseline levels of each channel per subject ranged from 0.45 to 2.25 μV for DUTP and from 0.48 to 2.57 μV for DUTA.

The means of the filtered baseline resting trials for each channel were 1.21 μV for DUTP

and 1.8 μV for DUTA. The coefficients of variation were 0.37 for DUTP and 0.45 for DUTA. Due to the variability of the baseline levels, the values for each subject and each channel were individually subtracted from subsequent trials prior to analysis of the data.

5.4.2 EMG Statistical Analysis Overview

EMG amplitude, averaged across all groups measured at both dominant (dynamic limb) upper trapezius channels was significantly different between trials, with significantly higher upper trapezius activation during the repetitive task relative to the standing trials. Unless otherwise stated, amplitude expressed in % is equal to reference voluntary electrical (RVE). RVE is the root mean square as a percentage of the root mean square EMG amplitude obtained during the reference voluntary contraction. Median frequency was significantly lower in upper trapezius of the dynamic limb during the repetitive task compared with pre-task and post-task standing. There were several significant interactions that are described in detail with each analysis, with the relevant channel. For the EMG analysis section, pre-task standing was considered Trial 1 (T1), the repetitive task was considered Trial 2 (T2) and post-task standing was named Trial 3 (T3). In the analysis of time in trial (early, late), standing trial results were averaged across the first and last half of each trial, while the first and last 70 s recorded during the repetitive task were compared. All effects are reported as significant at $p \leq 0.05$.

5.4.3 Research Question 1: WADII versus Healthy

The first of three research questions to be explored in this thesis was:

Do female WADII patients differ from female healthy controls with respect to dominant upper trapezius surface EMG amplitude and frequency, measured pre, post and during a repetitive upper limb task, performed by the dominant limb?

A three way mixed ANOVA, group (2) by trial (3) by time in trial (2) was performed for each channel for the dependant variables median frequency and mean EMG amplitude.

The results are presented by channel location and dependent variable.

Posterior fibres (DUTP): Mean EMG amplitude

The three-way ANOVA revealed a main effect of trial for mean EMG amplitude in DUTP ($F_{1,1, 28.6} = 264.2$, $p < 0.0001$) with Trial 2 amplitude being significantly higher than Trial 1 ($p < 0.0001$) and Trial 3 ($p < 0.0001$). There were no other main effects or interaction effects in the analysis of mean EMG amplitude for DUTP.

Anterior Fibres (DUTA): Mean EMG amplitude

Analysis revealed a main effect of trial for mean EMG amplitude in DUTA ($F_{1,0, 27.8} = 111.7$, $p < 0.0001$) with Trial 2 amplitude being significantly higher than Trial 1 ($p < 0.0001$) and Trial 3 ($p < 0.0001$). This was consistent with the findings for DUTP.

There was, however, a significant interaction effect between group and trial for DUTA mean amplitude ($F_{1,0, 27.8} = 5.441$, $p = 0.026$). Separate follow-up analysis for each of the two groups revealed that the effect of trial was still significant for both healthy ($F_{1,0, 9.1} = 44.023$, $p < 0.0001$) and WAD groups ($F_{1,0, 18.5} = 63.394$, $p < 0.0001$), again showing that the mean amplitude of Trial 2 was significantly higher than Trial 1 ($p < 0.0001$) and Trial3 ($p < 0.0001$).

The 95% Confidence Intervals for each group and trial are presented below in Figure 4 and Table 5. The significant group by trial interaction was due to group differences during the repetitive task. The WADII group had significantly lower amplitude, on average, during the repetitive task, compared to the healthy group ($F_{1, 27} = 4.6$, $p = 0.041$).

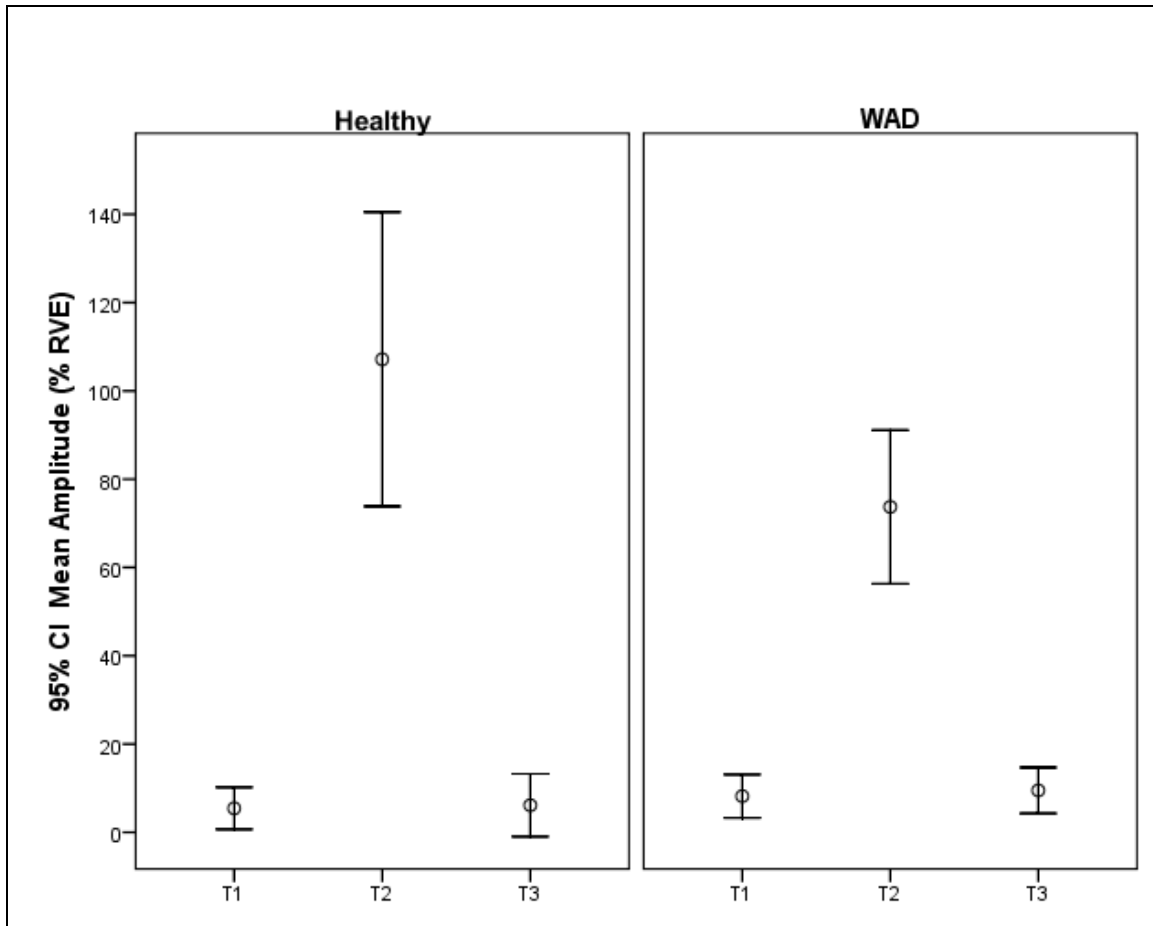


Figure 6 WADII vs. Healthy DUTA mean EMG amplitude (group by trial)

Table 5 DUTA 95% Confidence Intervals for mean EMG amplitude (% RVE)

Group	T1	T2	T3
Healthy	5.4 ± 4.1	107.2 ± 28.9	6.2 ± 6.2
WADII	8.2 ± 4.6	73.7 ± 16.2	9.5 ± 4.9

Posterior Fibres (DUTP): Median Frequency

The main effect of trial was significant for DUTP median frequency, ($F_{1.4, 37.8} = 9.584$ $p = 0.001$) with the mean of Trial 2 being significantly less than Trial 1 ($p = 0.001$) and less than Trial 3 ($p = 0.009$).

In the analysis of DUTP median frequency, there was also a significant effect between group and time in trial ($F_{1,27} = 5.734$, $p = 0.024$). Independent analysis of the healthy group revealed no main effect of trial and no main effect of time in trial. In contrast, the WAD group showed a significant main effect of trial ($F_{1,3,23.8} = 6.234$, $p = 0.014$), with Trial 2 median frequency being significantly lower than Trial 1 ($p = 0.014$) and Trial 3 ($p = 0.039$) and no main effect of time in trial. The significant interaction was not evident with secondary independent group analysis, rather, only when the groups were compared.

Figures 4 to 6 show that the differences in time in trial between the WADII and healthy groups were demonstrated within the pre and post-task standing trials rather than during the repetitive task. During pre-task and post-task standing the median frequency of the healthy group increased 10.4% between the first and last 2.5 minutes of the trial, while median frequency in the WADII Group declined by 5% during Pre-Task Standing and by 11.9% during post-task standing. During the repetitive task, median frequency declined by 0.5% in the healthy group and by 1.7% in the WADII Group, from the first 70 s to the last 70 s.

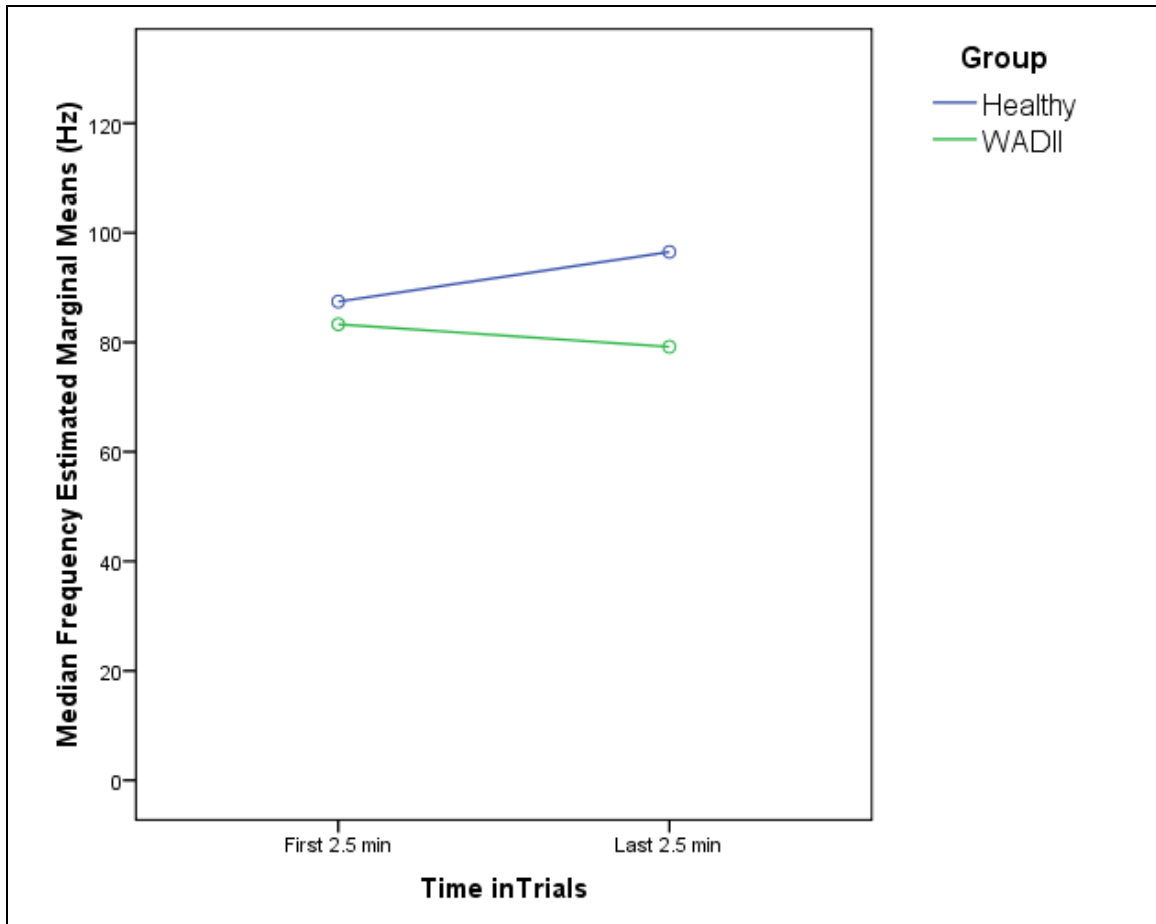


Figure 7 WADII vs. Healthy DUTP median frequency Trial 1 (group by time in trial)

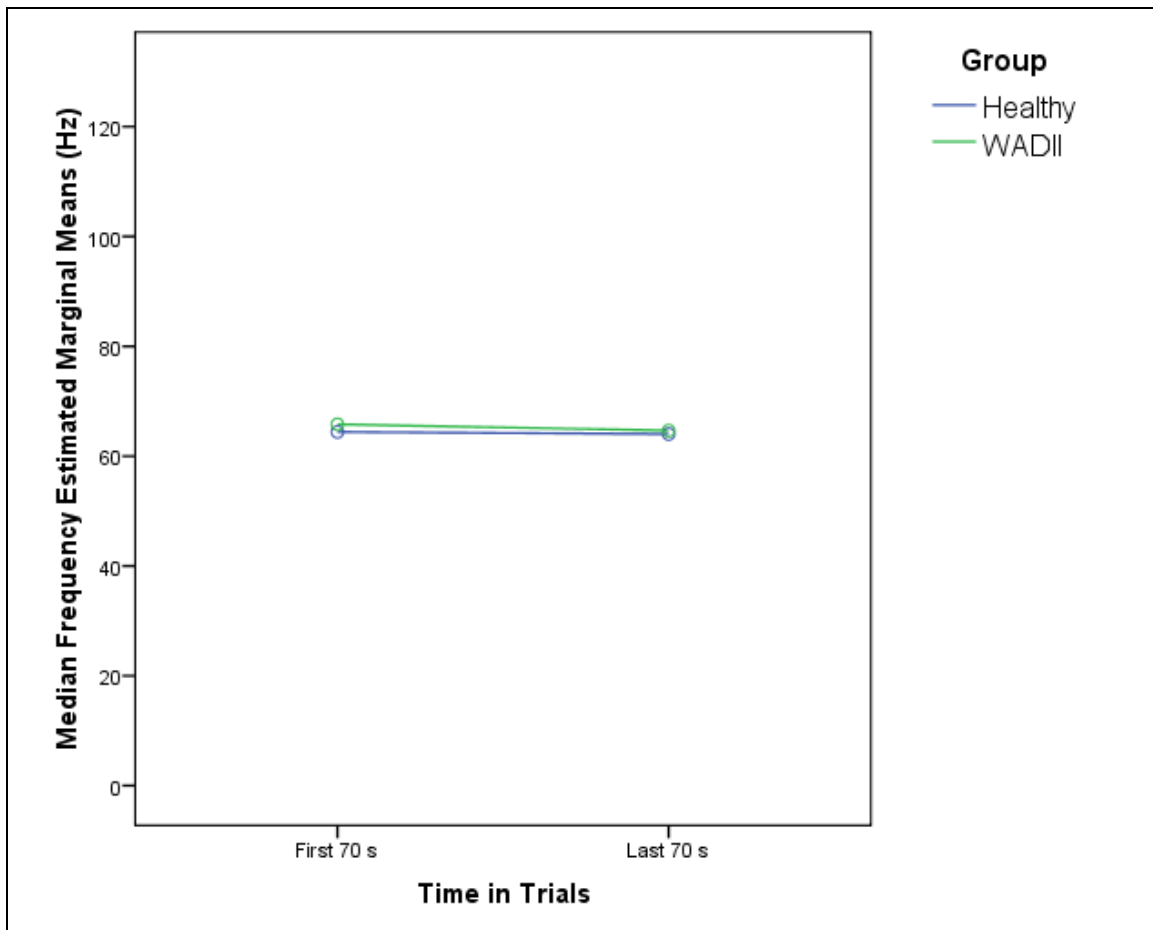


Figure 8 WADII vs. Healthy DUTP median frequency Trial 2 (group by time in trial)

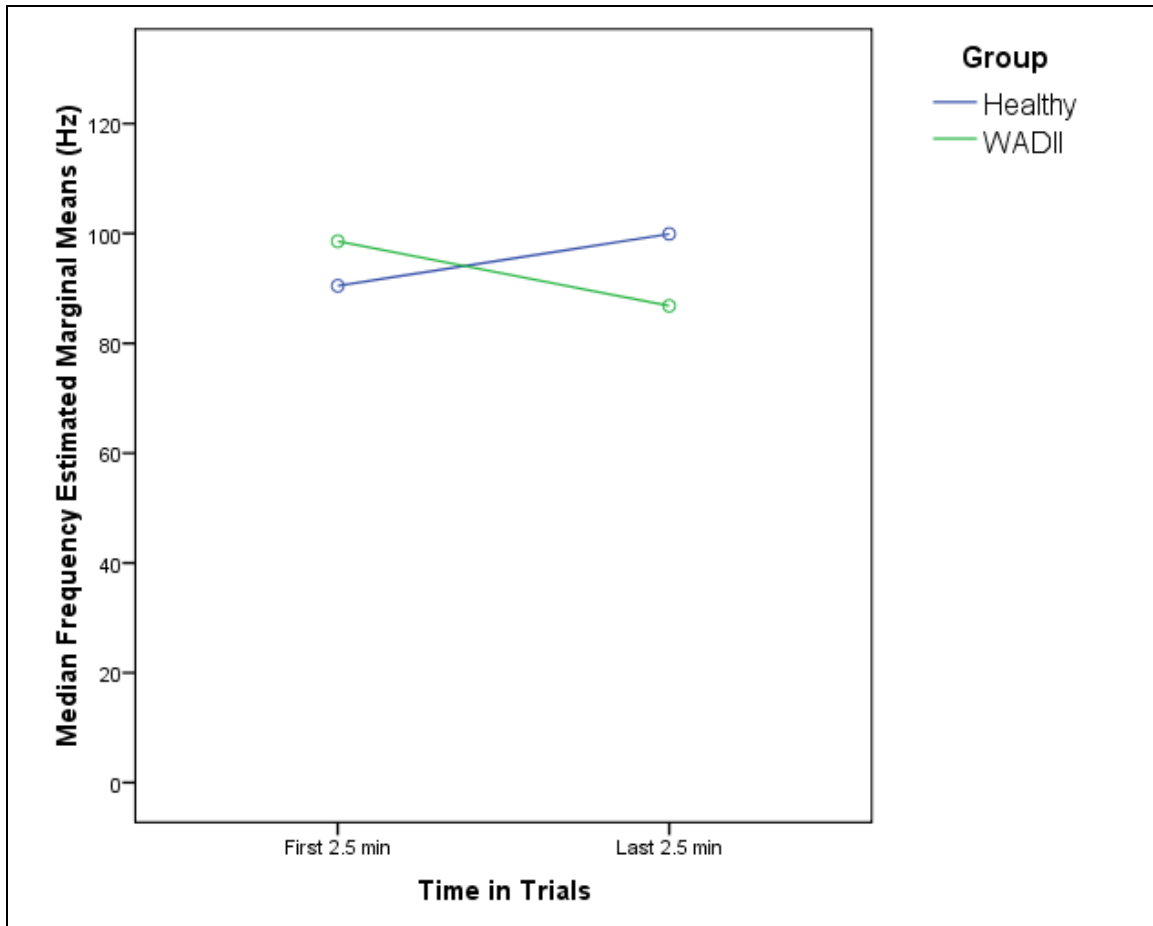


Figure 9 WADII vs. Healthy DUTP median frequency Trial 3 (group by time in trial)

Anterior Fibres (DUTA): Median Frequency

The main effect of trial was significant ($F_{1,1, 30.8} = 10.001$, $p = 0.003$). The mean of Trial 2 was significantly less than Trial 1 ($p = 0.013$), and Trial 3 ($p = 0.008$). All other main effects and interactions were non-significant.

5.4.4 Research Question 2a: Classification by Neck Disability Index Score

The second of three research questions to be explored in this thesis, was: Do subgroups of female WADII patients differ from each other and female healthy controls with respect to dominant upper trapezius surface EMG amplitude and frequency, measured pre, post and during a repetitive upper limb task when classified by NDI scores in to mild to moderate, 10-28, and moderate to severe disability, ≥ 30 ?

A comparison of the NDI groups with respect to demographics is presented prior to presentation of the results of the statistical analysis of the EMG data. A three-way mixed ANOVA, group (3) by trial (3) by time in trial (2) was performed for each channel for the dependant variables median frequency and mean EMG amplitude. There were 9 subjects in the NDI10-28 group and 10 in the healthy and NDI ≥ 30 groups. The results are presented by channel location and dependent variable.

NDI Group Demographics

Increased perceived disability in the NDI ≥ 30 group relative to the NDI10-28 group was confirmed by work status, with one of the ten participants having fully returned to work, in contrast with 8/9 in the NDI10-28 group having fully returned to work. See Table 6 for a comparison of group demographics. Medication intake was also higher in the NDI ≥ 30 group. The NDI ≥ 30 group was younger and reported a slightly higher number of symptoms as well as increased duration of symptoms in comparison with the NDI10-28 group, but these differences were not found to be statistically significant.

Table 6 Summary of demographics by NDI group

Variable	NDI10-28	NDI≥30
Age (y)	Mean 43.6 (sd 12.6) range 23-58	Mean 34.6 (sd 12.6) range 19-49
Time since MVA (y)	5 (sd 5)	5.4 (sd 6.7)
< 3 y Post MVA (%)	56	60
Direction of Impact (%)	Rear 56 Side 22 Front 0 Other 22 (front left 11, rear then front 11)	Rear 60 Side 10 Front 30 Other 10 (roll over down embankment)
Mean NDI score (range)	23 (sd 3.7) range 16-28	53 (sd 12.8) range 30-70
Pain (0-10)	mean 3.3 (sd 1.5) range 1-6	mean 6.5 (sd 1.8) range 2-8
Work Status (%)	Fully returned 89 Partially returned 11	Fully returned 10 * (after change in career due to MVA) Partially Returned 30 Not working due to MVA 40 Training for career change due to MVA 20

Variable	NDI10-28	NDI≥30
Worst Problem Neck or upper Back pain Including Muscle Tension (%; in past week)	89	80
Number of Symptoms	10 (sd 5) range 2-17	11 (sd 5) range 3-22
Taking Medications related to MVA (%)	33	70

Posterior Fibres (DUTP): Mean EMG Amplitude

The main effect of trial was significant in the primary analysis ($F_{1,1, 27.7} = 282.282$, $p < 0.0001$), as noted with WAD versus healthy, and with follow-up analysis for each group ($p < 0.0001$), with Trial 2 demonstrating greater EMG amplitude than Trial 1 and Trial 3 ($p < 0.0001$).

There was also a significant interaction between group and trial for the analysis of DUTP mean amplitude ($F_{2,1, 27.7} = 3.415$, $p = 0.045$). Independent group, repeated measures ANOVA revealed a significant interaction between trial and time in trial ($F_{1,3, 11.6} = 4.839$, $p = 0.042$), only in the NDI≥30 group. In the NDI≥30 group, mean EMG amplitude rose by 33% between the first and last halves of Trial 1, and by 36% between the first and last halves of Trial 3, while it declined by 5.8% during the repetitive task. There were no other significant main effects or interactions in the independent group analyses.

Figure 10 depicts the behaviour of the three groups from trial to trial. The NDI10-28 and NDI≥30 groups showed patterns which differed from each other and the healthy

group. Pre-task and post-task, the $\text{NDI} \geq 30$ group had higher EMG amplitude than the $\text{NDI} 10\text{-}28$ and healthy groups, with confidence intervals that were larger and widely overlapped those of both other groups. During the repetitive task, the mean for the $\text{NDI} \geq 30$ group was similar to that of the healthy group, but showed a greater amount of variability, whereas, the $\text{NDI} 10\text{-}28$ group, demonstrated lower EMG amplitude during the task relative to the healthy and $\text{NDI} \geq 30$ groups, as well as demonstrating greater variability than the healthy group.

Secondary analysis, using one-way ANOVA, to analyze each trial, showed no significant differences overall between groups pre-task and post task, but significant between group differences during the task ($F_{2,26} = 3.363$, $p = 0.05$), with the $\text{NDI} 10\text{-}28$ group demonstrating EMG amplitude which was significantly lower during the repetitive task relative to healthy controls (Games Howell post hoc test, $p = 0.046$) but not significantly different from the $\text{NDI} \geq 30$ group.

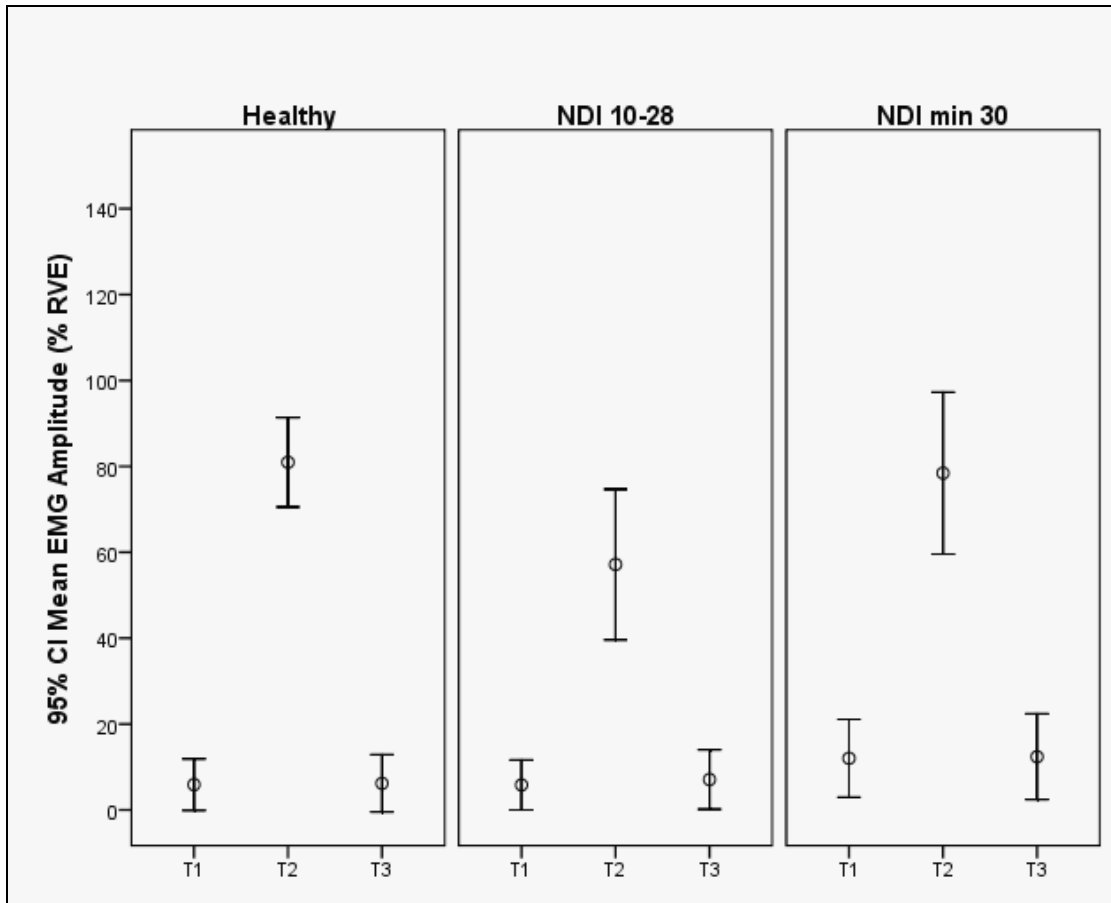


Figure 10 NDI classification DUTP mean EMG amplitude (group by trial)

Anterior Fibres (DUTA): Mean EMG Amplitude

The three-way ANOVA for mean EMG amplitude in DUTA revealed a main effect of trial ($F_{1,0, 26.8} = 103.022$, $p < 0.0001$) with Trial 2 amplitude being significantly higher than Trial 1 ($p < 0.0001$) and Trial 3 ($p < 0.0001$). In contrast with the WADII versus healthy analysis, there were no other significant main or interaction effects in the analysis of mean EMG amplitude, for DUTA.

Posterior Fibres (DUTP): Median Frequency

The three-way ANOVA for median frequency in DUTP revealed a main effect of trial ($F_{1,4, 36.4} = 9.474$, $p = 0.002$) with Trial 2 frequency being significantly lower than Trial 1 ($p < 0.003$) and Trial 3 ($p < 0.008$). In contrast, with the WADII versus healthy analysis,

there were no other significant main or interaction effects in the analysis of median frequency for DUTP.

Anterior Fibres (DUTA): Median Frequency

The three-way ANOVA for median frequency in DUTA revealed a main effect of trial ($F_{1.2, 29.8} = 9.763$, $p = 0.003$) with Trial 2 frequency being significantly lower than Trial 1 ($p = 0.012$) and Trial 3 ($p = 0.010$). This was consistent with the findings when comparing NDI groups for median frequency with DUTP.

5.4.5 Research Question 2b: Sterling Classification

The third of three research questions to be explored in this thesis, was: Do subgroups of female WADII patients differ from each other and female healthy controls with respect to dominant upper trapezius surface EMG amplitude and frequency, measured pre, post and during a repetitive upper limb task when classified by subgrouping as per a modified Sterling clinical classification system (WADIIA, WADIIB, WADIIC)? [32]

A comparison of the Sterling groups with respect to demographics is presented prior to presentation of the results of the statistical analysis of the EMG data. A three-way mixed ANOVA, group (4) by trial (3) by time in trial (2) was performed for each channel for the dependant variables median frequency and mean EMG amplitude. There were 10 subjects in the healthy group, 6 subjects in the WADIIA group, 8 subjects in the WADIIB group and 5 subjects in the WADIIC group. The results are presented by channel location and dependent variable.

Sterling Group Demographics

The assignment to Sterling group, WADIIA, WADIIB or WADIIC was determined by clinical assessment. See Section 4.5 for criteria for group assignment and Section 4.7.3 for the procedures used as well as rationale for same.

Although there was a wide range of symptom duration for each group, the WADIIC group had a shorter mean duration of symptoms, 2 years (sd 1.6) versus 6.6 (sd 10.6) for WADIIB and 6.9 (sd 10.6) for the WADIIA group. See Table 7. Eighty percent of the WADIIC group had an MVA less than three years prior to the study. In contrast the percentage of the group who were less than three years post MVA was 63% for the WADIIB group, and 33% for the WADIIA group. Due to the variability with respect to symptom duration in all three groups, the differences in mean symptom duration between groups were not statistically significant ($F_{3,27} = 2.950$, $p = 0.053$).

All five women in the WADIIC group were drawn from the pool of volunteers with NDI scores of 30 or more (scores ranged from 38-70). See Table 4 regarding distribution of volunteers in NDI and Sterling groups. On average, the WADIIA group had less self reported neck pain related disability (lower NDI scores) than the WADIIB and WADIIC groups. As a result of this distribution, there were clear differences with respect to percent of the groups fully returned to work, WADIIA was 89%, WADIIB was 57% and WADIIC was 0%. There was a higher percentage of participants in the WADIIC group taking medication for symptoms from their MVA, 80% versus 57% in the WADIIB, and 50% in the WADIIA group. See Table 7 for a comparison of demographics between Sterling groups.

Table 7 Summary of demographics by Sterling group

Variable	WADIIA (n = 6)	WADIIB (n = 8)	WADIIC (n = 5)
Age	Mean 43.5 (sd 10.7) range 26-57	Mean 41.0 (sd 13.3) range 20-58	Mean 29.8 (13.9) range 19-49
Time since MVA (y)	6.9 (sd 10.6) range 2-18.5	6.0 (sd 6.5) range 0.8-15.9	2 (1 6) range 0.9-4.8
< 3 y Post-MVA (%)	33	62	80
Direction of Impact (%)	Rear 33 Side 17 Front 17 Other 33	Rear 63 Side 13 Front 13 Other 13	Rear 60 Side 20 Front 20 Other 0
NDI score	Mean 29.7 (14.8) range 16-58	Mean 38.3 (20.1) range 22-70	Mean 51.6 (18) range 38-64
Pain Level	Mean 3.2 (1.9) Range 1-6	Mean 5.3 (2.1) range 3-8	Mean 6.8 (0.837) range 6-8
GHQ-28	Mean 18.3 (sd 3.5) range 13-21	Mean 34.0 (sd 14.5) range 24-67	Mean 37.8 (sd 6.7) range 30-46
IES	Mean 1.2 (sd 1.6) range 0-4	Mean 5.0 (sd 7.9) range 0-20	Mean 20.6 (sd 7.4) range 12-29

Variable	WADIIA (n = 6)	WADIIB (n = 8)	WADIIC (n = 5)
Work Status (%)	Fully returned 89 Partially returned 11 Not working due to MVA 0	Fully returned 63* Partially returned 14 Not working due to MVA 29 * changed career before RTW 13	Fully returned 0 Partially Returned 60 Not working due to MVA 20 Training for career change due to MVA 20
Worst Problem Neck or upper Back pain Including Muscle Tension (% in past week)	83	88	80
Number of Symptoms	8.8 (sd 5.4) range 2-17	11.1 (sd 3.9) range 6-17	10.4 (sd 5.2) range 3-22
Taking Medications related to MVA (%)	50	63	80

Posterior fibres (DUTP): Mean EMG amplitude

The three-way ANOVA revealed a main effect of trial for mean EMG amplitude in DUTP ($F_{1,1, 26.3} = 260.865$, $p < 0.0001$) with Trial 2 amplitude being significantly higher than Trial 1 ($p < 0.0001$) and Trial 3 ($p < 0.0001$). In contrast with the analysis of DUTP mean amplitude using the NDI Classification, there were no other main or interaction effects in the analysis of mean EMG amplitude for DUTP, using the Sterling classification.

Anterior Fibres (DUTA): Mean EMG amplitude

The three-way ANOVA revealed a main effect of trial for mean EMG amplitude in DUTP ($F_{10, 25.8} = 260.865$, $p < 0.0001$) with Trial 2 amplitude being significantly higher than Trial 1 ($p < 0.0001$) and Trial 3 ($p < 0.0001$). In contrast with the analysis of DUTA mean amplitude in the WAD versus healthy analysis, there were no other main or interaction effects in the analysis of mean EMG amplitude for DUTA, using the Sterling classification.

Posterior Fibres (DUTP): Median Frequency

Analysis of median frequency in DUTP revealed a main effect of trial ($F_{1.4, 35} = 8.1$, $p = 0.003$) with Trial 2 frequency being significantly lower than Trial 1 ($p = 0.006$) and Trial 3 ($p < 0.016$). In contrast with the WADII versus healthy analysis, there were no other significant main or interaction effects.

Anterior Fibres (DUTA): Median Frequency

Analysis of median frequency in DUTA revealed a main effect of trial ($F_{1.2, 29.4} = 12.746$, $p = 0.001$) with Trial 2 frequency being significantly lower than Trial 1 ($p = 0.003$) and Trial 3 ($p < 0.004$). Consistent with the WADII versus healthy and NDI group analysis of median frequency in the anterior fibres of the dominant limb, there were no other significant main or interaction effects for DUTA, using the Sterling subclassification.

6. Discussion

6.1 Research Question 1: WADII versus Healthy

There was evidence of differences between a group of 10 healthy women and 19 women with WADII, with respect to differences in mean amplitude and median frequency measured before during and after a unilateral, repetitive upper limb task. Specifically, there were between group differences, in anterior fibres of upper trapezius of the dynamic (dominant) limb in mean EMG amplitude, which differed between trials, and, differences between groups, in the posterior fibres of upper trapezius of the dominant limb, regarding pattern of change of median frequency within trials.

During the repetitive task, the whiplash injured women on average, demonstrated reduced recruitment of upper trapezius relative to healthy controls in the anterior fibres. The interaction between group and trial was not significant for mean EMG amplitude in the posterior fibres. The finding with respect to lower EMG amplitude in the WADII group during the repetitive task was comparable to Falla et al [44], who reported significantly lower activation of upper trapezius of the dynamic limb during the repetitive task, measured for 5 s intervals at 10s, 60 s and 120 s, when comparing 10 women with neck pain persisting for 3 months post MVA, with 10 healthy women.

In contrast with three similar studies [22,43,44], there was no evidence that the WADII women had higher post-task EMG amplitude compared with pre-task that differed from the control group. This was similar to the findings reported by Nederhand et al in 2003 for a sample of 92 WADII participants. They had no control group and considered pre minus post values greater than zero to be abnormal. [28] The different findings could

have been due to differences in sampling, longer duration of measurements pre and post-task in the current study and in Nederhand et al 2003, or filtering of cardiac signals in the current study, the absence of which could have confounded previous study findings. For example, Nederhand et al in 2000 [22] had a WADII sample with mean NDI scores that were higher than those in this study. The 95% CI for Nederhand et al 2000 was 52 ± 12 , and in this study, the 95% CI for NDI scores was 39 ± 8 . Scores were similar to this study in the Falla et al study, 42 ± 2 [44], lower for Nederhand et al 2003 [28], 21 ± 4.3 , and not reported in Nederhand et al 2002. [22] Nederhand et al in 2000 measured EMG for 10 s pre and post task and Falla et al analyzed EMG for the peak 1 s of a 5 s epoch pre and post task, while in this study EMG was averaged over the first and last 2.5 minutes of pre and post task standing. If differences in ability to relax post task, were of short duration, then such differences could have been missed with the longer time averaging in this study. The difference may be partially explained by continuous versus intermittent sampling. In this study, EMG was recorded continuously pre, during and post-task, while all four of the previous studies reported on EMG sampling over a period of 1 s [44] or 10 s at various intervals. [22,28,43] None of the previous studies mentioned or managed cardiac contamination of the EMG signal.

The differences between groups in median frequency, in the posterior fibres of upper trapezius, with respect to differences early and late within the trials, were particularly evident during the pre-task and post-task standing trials. The interaction between groups and time in trial was non-significant in the anterior fibres of the same muscle.

Fatigue has been defined and measured in many different ways, however the definition applicable to the findings of this study is, increased muscle recruitment and/ or declining

median frequency over the course of the trial, in the absence of increasing load or other task demands. [17,90] Declining median frequency, in combination with rising EMG amplitude over time is a classic sign of fatigue. [36,54,57,90] Table 8 compares changes within trials between groups with respect to median frequency and mean amplitude in the posterior fibres of upper trapezius of the dynamic limb, and shows that the WADII group demonstrated a pattern consistent with fatigue, particularly during the standing trials, that was larger post-task than before performance of the repetitive task. This pattern was not seen in the healthy group for the posterior fibres, in any of the three trials. There was no evidence of differences between the groups in median frequency of the anterior fibres.

Table 8 DUTP percentage change in EMG amplitude (Amp) and median frequency (Freq) relative to first half of trial

Group	Pre-task Standing T1		Westgaard Task T2		Post-task Standing T3	
	Freq	Amp	Freq	Amp	Freq	Amp
Healthy	10.4	-2.9	-0.5	-2.6	10.4	-9.2
WADII	-4.9	33.2	-1.7	-2.1	-11.9	40.1

6.2 Research Question 2a: Classification by Neck Disability Index Score

Do subgroups of female WADII patients differ from each other and female healthy controls with respect to right and left upper trapezius surface EMG amplitude and frequency, measured pre, post and during a repetitive upper limb task when classified by NDI scores in to moderate (10-28) and moderate to severe disability (≥ 30)?

The answer is yes, in that classifying by disability scores revealed previously unobserved differences between groups with DUTP mean amplitude, which differed across trials. However, two interaction effects that were significant when comparing WADII versus healthy, were non-significant when the WADII group was subclassified by NDI scores (DUTA mean amplitude group by trial and DUTP median frequency group by time in trial).

Greater differences, relative to healthy controls, were demonstrated in the group with lower disability levels in EMG amplitude, measured from DUTP, during the repetitive task. The NDI10-28 group showed lower recruitment levels relative to the healthy controls, while the $NDI \geq 30$ group showed overall recruitment levels that were not significantly different from the healthy control group.

Independent analysis of the $NDI \geq 30$ group also revealed a significant interaction between trial and time in trial of DUTP that was not demonstrated in the other two groups. In the $NDI \geq 30$ group, mean EMG amplitude rose by 33.2% between the first and last half of Trial 1, and by 36.4% between the first and last half of Trial 3, while it declined by 5.8% during the repetitive task. Although both WADII groups showed patterns of declining frequency and increasing amplitude from the first to last half of the standing trials consistent with fatigue, the $NDI \geq 30$ group differences in amplitude within trials were likely significant to due % RVE changes associated with higher initial RVE values relative to the NDI10-28 group. See Table 9 for amplitude and median frequency changes for each group from first to last half of each trial.

Table 9 DUTP percentage change in EMG amplitude (Amp) and median frequency (Freq) relative to first half of trial (NDI groups)

Group	Pre-Task Standing T1		Westgaard Task T2		Post-Task Standing T3	
	Amp	Freq	Amp	Freq	Amp	Freq
Healthy	-2.9	10.4	-2.6	-0.5	-0.1	10.4
NDI10-28	33.1	-4.1	3.7	-1.4	47.9	-6.9
NDI\geq30	33.2	-5.7	-5.8	-2.0	36.4	-16.2

These findings indicate there were differences between the two NDI groups, however, the findings in DUTP were in contrast with a negative correlation between NDI scores and EMG amplitude reported by Falla et al, in upper trapezius of the dynamic limb in women with WADII relative to healthy controls, during the repetitive task. [44] This information, in combination with the fact that two interaction effects, that were significant when comparing WADII versus healthy, were non-significant when the WADII group was subclassified by NDI scores, suggests that subclassifying by disability scores may not be a reliable way of differentiating between female WADII subgroups with upper trapezius recruitment patterns that differ from patterns found in healthy women.

6.3 Research Question 2b: Sterling Classification

Do subgroups of female WADII patients differ from each other and female healthy controls with respect to dominant upper trapezius surface EMG amplitude and frequency, measured pre, post and during a repetitive upper limb task when classified by subgrouping as per a modified Sterling clinical classification system (WADIIA, WADIIB, WADIIC)? [32]

Subgroups of female WADII patients did not differ from each other or female healthy controls with respect to dominant limb upper trapezius surface EMG amplitude or median frequency, measured from posterior and anterior fibres pre-task, post-task and during a repetitive upper limb task when classified using a modified Sterling clinical classification system.

6.4 Subclassification of WADII Summary

This study showed that NDI scores are not a good predictor of level of upper altered trapezius recruitment patterns. The group with lower disability scores in this study demonstrated reduced amplitude relative to controls, for DUTP mean amplitude, during the repetitive task, while the group with NDI scores of 30% and higher did not. This finding is in contrast with Falla et al [44] who reported an inverse correlation between NDI scores and EMG amplitude during the repetitive task. The conflicting findings with respect to direction of correlation with NDI scores could have reflected a chance difference in sample characteristics in the two studies. However, it could also have reflected differences in duration of EMG samples. The current study recorded EMG continuously and results reflected the entire duration of the repetitive task while Falla et

al compared the means calculated from the peak 1 s of 5 s EMG epochs at 10, 60, 120 s during the repetitive task.

Nevertheless, significant differences, which likely represented fatigue, were demonstrated within trials, only in the $NDI \geq 30$ group for mean EMG amplitude measured from DUTP. This effect was particularly evident within the static standing trials and may have impacted recruitment levels during the repetitive task.

Subclassification using the Sterling system was unhelpful in differentiating WADII participants with altered upper trapezius recruitment patterns, before during and after the repetitive task. The findings when subgrouping by disability scores were consistent with other findings of heterogeneity in WADII. [2,4,11-21] However, the overall differences between the WADII group and healthy controls in measures of mean amplitude and median frequency, before during and after a repetitive upper limb task indicated the differences were associated with the condition of persistent neck pain post MVA, rather than disability levels or the clinical patterns selected for this study.

6.5 Underlying Mechanism for Observed Differences in Upper Trapezius Recruitment

Differences between 19 women with WADII and 10 Healthy controls were evident in upper trapezius of the dominant limb before, during and after the repetitive task.

Reduced recruitment during the repetitive task in the anterior fibres of upper trapezius was demonstrated. Additionally, differences in behaviour of median frequency over time differed significantly between the WADII group and the healthy group, in the posterior fibres of upper trapezius of the dominant limb. Using the NDI Classification revealed significant group differences with respect to behaviour of mean EMG amplitude in the

posterior fibres that differed between trials, that was not significant when comparing WADII with healthy controls ($p = 0.054$). This fact, in combination with variable findings in this and four previous studies [22,28,43,44], indicates, that although several abnormalities in muscle recruitment in WADII have been demonstrated, their presence and magnitude is highly variable between individuals reporting persistent neck pain post MVA. In this study, differing results were found in the posterior and anterior fibres of upper trapezius of the dominant limb, with respect to differences between the whiplash injured and healthy groups, indicating that results from one recording site cannot be generalized to the entire muscle. Increasing the number of recording sites improved the sensitivity and gave additional context to the findings. Previous studies using the Westgaard Task, with WADII patients recorded only from the posterior electrode site and did not compare mean or median frequency. [22,28,43,44]

Mechanisms proposed for reduced EMG amplitude with physical loading include altered input from injured cervical tissues [17,19,27,45-48], altered proprioception due to pain or inflammatory mediators [19,45], particularly, in the presence of peripheral or central sensitization [46], segmental inhibition of alpha motoneurons due to pain [17,27,46], inhibition related to fear of movement/fear of pain [2,28,46], local muscle injury [17], and or muscle pain [49], altered postural control associated with muscle fatigue, [17,45] and altered supraspinal inhibition of motor cortex and or alpha motor neurons due to pain [46,50] and or anxiety. [17,46,50,91] Mosely and Hodges theorized that subtle changes in muscle recruitment patterns in association with sensitization of local tissue (peripheral and or central sensitization) may become a self perpetuating source of further pain and abnormalities of motor control. [46] Arendt-Nielsen supported

this theory based on a review of the literature in the area of sensory changes and altered motor control in pain states. [92] Mosely and Hodges, Richardson, and Sterling et al have all described scenarios in which motor abnormalities may begin in association with pain but persist once pain has resolved, making it important to evaluate and rehabilitate normal motor patterns in addition to providing interventions targeted towards resolving or alleviating pain. [27,46,93]

As WADII has been found to be a heterogeneous group, it is possible that the mechanisms for these abnormalities of muscle recruitment overlap and differ amongst individuals. [46] In this study abnormal recruitment patterns were present in people with various levels of disability and a variety of clinical presentations. However, it is likely that inhibition of muscle recruitment begins early post trauma in response to pain and persists as the pain persists.

Reduced activation of muscle during a dynamic task has been described by Arendt-Nielsen [92] and reported by Falla et al [49] in the presence of experimentally induced muscle pain in healthy individuals, and, Arendt-Nielsen reported that evidence to date is consistent with reduced central drive of the postural muscles in response to the pain.

Abnormalities with respect to changes in median frequency within trials were found in the posterior fibres of upper trapezius of the dominant limb. Declining frequency in association with increasing amplitude was noted in the WADII group, particularly during the standing trials with larger changes post-task than pre-task. This pattern is consistent with fatigue in the WADII group and was not seen in the healthy group.

A similar pattern was also observed in EMG measured from the posterior fibres in the $NDI \geq 30$ group during the pre-task and post task standing trials. Increased fatiguability of

muscle has been found using experimental muscle pain in healthy individuals [92] so could have been related to the presence of pain; however, it could also have been a result of deconditioning. This finding is intriguing, given the low demand on upper trapezius in static standing (95% CI for healthy subjects for DUTP in T1 were $5.4 \pm 5.7\%$ RVE and in T3 were $6.2 \pm 6.5\%$ RVE), and the fact that patterns of fatigue were not seen during the repetitive task. The difference between trials may have reflected augmented central drive from the motor cortex and reticular system associated with voluntary limb movement, versus primarily vestibulospinal inputs during static standing. Fewer motor units were recruited in standing and therefore may have been more susceptible to fatigue. In the WADII versus healthy analysis, the effect was increased post-task, (steeper declines in median frequency post-task versus pre-task in the WADII group, indicating the repetitive task also contributed to fatigue in post-task standing.

In contrast with altered upper trapezius muscle recruitment post-whiplash, changes in recruitment patterns of the superficial and deep neck flexors have been consistent and have shown a correlation with NDI scores. [27,42,44,58,59,94,95]

6.6 Limitations

There were several limitations of the study including small sample size and cross-sectional design. Surface EMG is incapable of measuring differences in deeper neck muscles, which are also likely to be impaired. In addition multiple comparisons were made with no adjustment to the family-wise error rate (alpha was kept at 0.05), which increased the risk of a Type I Error. Digital filters were applied, which did necessitate some loss of data but the filters were applied consistently to all recordings, which should not have impacted the results.

Upper trapezius recruitment patterns do not differ significantly and consistently amongst patients with neck pain and there is large variability amongst healthy subjects. Therefore, the dependant variables selected, mean EMG amplitude and median frequency, made it difficult to distinguish abnormal patterns from normal variability. There were several outliers, even in the healthy group. Although they were from different subjects on different trials and different channels it biased the healthy mean upwards and increased the standard deviations, increasing the risk of Type II error during the standing trials and risk of Type I error during the repetitive task.

It is possible that differences in complaints of muscle pain and fatigue associated with activity lay less in recruitment patterns and more in differences in muscle metabolism. [96] EMG is not capable of detecting such differences. For example, Nederhand et al (2000) evaluated 10 s epochs at 10, 60 and 120 s and found that mean EMG amplitude at three time points were not significantly different, despite WADII volunteers complaining of aggravation of pain and stiffness. [22]

Clinical tests to screen for WADII status, as well as completion and scoring of the NDI to confirm eligibility should have been done prior to completion of EMG, and performed on healthy subjects as well, to improve study efficiency and reduce the burden on ineligible volunteers.

As this work was exploratory, there was no attempt to link changes in muscle recruitment patterns with function. It is not known which functional limitations, if any, are associated with the differences in muscle recruitment described.

Participants performed the repetitive task with their dominant limb which might not have painful. Fifteen out of nineteen WADII participants had bilateral neck pain and one

had unilateral pain on their dominant side, however, results could have been impacted by the three participants that had unilateral neck pain on their non-dominant side.

6.7 Directions for Future Research

This and other research indicates that surface EMG assessed on upper trapezius can be helpful in delineating differences between WADII subjects and controls before during and after a task requiring sustained activation of upper trapezius, so it is a useful avenue of research to pursue further. [22,43,44] At the risk of having subjects focus more on pain, symptoms should be monitored at prescribed time points throughout trials, in order to determine the intensity of provocation of the task. A repetitive task involving bilateral limb movements might be preferable, in order to better assess changes in recruitment in upper trapezius of both sides. The bilateral repetitive shoulder flexion task used by Falla et al in 2006 could be a suitable task. [49] Measures should assess differences in changes over time, within trials, and between trials, as this seems to be less variable than the absolute values for each trial. Ideally participants should be assessed on different days to determine test-retest reliability, and a protocol designed to provoke fatigue should be assessed on two separate occasions so as not to confound the results. A variable demand (physical and psychological) motor task should also be included, but caution must be exercised regarding exacerbation of symptoms, and reduced activity tolerance in many WADII patients with persistent pain. Larger studies, involving both genders and stratified by age group should be done to establish norms.

The Impact of Events Scale should be administered to explore the impact of post-traumatic stress, and to differentiate those that may have increased motor drive from this clinical syndrome, that is associated with hyperarousal. [97-99] The Patient Specific

Functional Scale should also be administered to determine individual physical limitations associated with abnormalities in muscle recruitment. Arendt-Nielsen et al [92], and Mosely and Hodges [46] advised inclusion of sensory testing, as was done in this study, to better understand sensitization of muscle afferents and altered motor control in pain patients. Due to heterogeneity of WADII patients and potential for multifactorial influences, a thorough evaluation of psychological and physical impairments should be included incorporating such measures as evaluation of perceived threat from pain, fear of pain/reinjury. [13,14,46] Ultimately motor control tests that could be administered by clinicians would be the ideal and tests that can be administered in the community are superior to having all subjects travel to one location, as many volunteers expressed a desire to avoid travel due to potential increases in neck pain. Surface EMG has potential as a clinical evaluation tool.

Once a reliable measurement protocol exists and norms are established, the ability of interventions to impact the abnormalities of muscle recruitment and function, such as EMG biofeedback [36], to train amplitude control, and home based exercise programs should be assessed, for example targeting endurance in upper trapezius, and other relevant muscles. In both types of studies, the researcher should control for, or evaluate current use of upper body, including occupational and recreational demands to adjust for training effects at baseline. Further evaluation regarding reduced ability to relax post task, which includes cardiac filtering, should be carried out, to determine whether the difference in this study, with respect to impaired ability to relax post-task was related to filtering or sample characteristics. [28,43,44]

Other avenues of exploration that may have merit, include use of real-time ultrasound to evaluate deeper muscle contraction, fine wire EMG, microvascular, or biochemical studies to improve understanding of relationships between motor control, local tissue changes, circulatory control and neck pain. Careful study of the vast amount of literature regarding occupational trapezius myalgia, low back pain and chronic pain, would be required, prior to embarking on such a study to ensure a sound hypothesis and increased likelihood of definitive answers. There are many unanswered questions and opportunities for research regarding abnormalities of upper trapezius recruitment and optimal interventions. Any studies in this area must recognize these recruitment changes occur in the context of complex and variable clinical patterns and incorporate measurement of concurrent, relevant impairments. [13,14,19,46,64,100,101]

7. Appendices

Appendix 7.1 Summary of Excluded Participants (Healthy and WAD)

Table 10 Summary of reasons for exclusions of healthy volunteers

Reason for Exclusion	Number Excluded
Not Healthy	1
Gender	6
Age	0
Previous Neck Pain Treatment	5
Current Neck or Upper Limb Pain or Functional Impairment	0
Medication	1
Central Nervous System Disorder	0
Total	13

Table 11 Summary of reasons for exclusion of WAD volunteers

Reason for Exclusion	Number Excluded
Gender	4
Age	1
Neck or Upper Back Pain Resolved	2
Neck Pain not Definitely Related to MVA	17
Time to Onset of Pain > 48 h	3
< 6 Months Post-MVA	7
Concussion Related to MVA or Known Disorder of CNS	9
Sought Professional Treatment for Neck or Back Pain in Month Prior to MVA	4
Not Willing or Able to Discontinue Medication for 12 h Prior to Data Collection Which Could Affect Pain Intensity or Ability to Activate Muscles	1
WADIV	0
WADIII	7
History of Neck Surgery	2
Widespread Pain Prior to MVA	0
Latex Allergy	0
NDI < 10	1
Enrolment complete in NDI Category of Participant	1
Total	59

Appendix 7.2 WADIIA, B, C Criteria as per Sterling 2004

Table 12 Summary of WADIIA, B, C criteria as proposed by Sterling in 2004

	WADIIA	WADIIB	WADIIC
Subjective Complaints			
neck pain	√	√	√
Motor Abnormalities			
1. ↓ Mobility	√	√	√
2. Altered Muscle recruitment			
a. Impaired CCFT	√	√	√
b. Increased Joint Positioning Error (relocation to neutral)	x	x	√ √
Psychological Impairments			
1. elevated distress			
a. ↑ GHQ-28	x	√ * ⁵	√
b. ↑ TAMPA	x	√ *	√
c. elevated levels of (acute) “post-traumatic stress”			
↑ IES	x	x	√ *
Sensory Impairments			
a. local cervical mechanical hyperalgesia	√	√	√
b. generalized or multimodal) hypersensitivity (mechanical, thermal) including increased sensitivity to brachial plexus tension test	x	x	√ *
Autonomic Impairments	x	x	possibly

⁵ * denotes distinguishing feature according to Sterling 2004 [32]

Appendix 7.3 Power Analysis

The sample size for each group was selected using G*Power [102] and inputting standard deviations for pre to post change as per results from Nederhand et al 2000 [22] for post-task EMG amplitude minus pre-task EMG amplitude which was 5.3 (% RVE) for the dynamic side and 6 (actual 5.6) for the stationary side. See the table below comparing the values from Nederhand et al (2000) with the values input to G*Power for sample size calculation. An assumption was made that the standard deviations of the differences pre to post-task would be closer to that of the control group if, as planned, the WAD sample was subgrouped.

Table 13 Comparison of values used in power analysis versus values reported by Nederhand et al 2000

Group	Actual Dynamic Side Mean (sd) Nederhand et al 2000 [22]	Belot- Dynamic Side Estimate Mean (sd)
HC	0.5 (5.3)	0.5 (5.3)
WAD	not subgrouped 9.4 (8.2)	6 (5.3) 10 (5.3) 13 (5.3)

The results were as follows:

Dynamic Side

F tests - ANOVA: Fixed effects, omnibus, one-way

Analysis: A priori: Compute required sample size

Input:	Effect size f	= 0.883
	α	= 0.05
	Power	= 0.95
	Number of groups	= 4
Output:	Non-centrality parameter λ	= 21.851
	Critical F	= 3.009
	Numerator df	= 3
	Denominator df	= 24
	Total sample size	= 28
	Actual power	= 0.964

The active side power calculations indicated 7 people per group would give a 95% probability of detecting a significant overall between-group difference, however, the true variability was unknown, particularly in the WAD group, consequently the planned size of each group was increased to 10.

Appendix 7.4 Regression Formulas for Decision Making Regarding Impaired Cervical Active Mobility

Table 14 Regression formulas and variables to determine lower bound of 95% CI for female norms
($Y = a + b * \text{age}$)

Direction	a (degrees)	b
Flexion	62.9	-0.4
Extension	92.9	-0.5
Left Lateral Flexion	52.5	-0.4
Right Lateral Flexion	55.4	-0.4
Left Rotation	78.5	-0.4
Right Rotation	83.7	-0.4

Appendix 7.5 Questionnaires

Appendix 7.5.1 Participants with Neck Pain (Demographics, Work and Health)

A. Demographics (Section A is identical to the healthy subject demographic form)

Please fill in the blanks for the statements below:

1. My age in years, today is _____
2. My height is _____ m/cm or _____ ft/in
3. My weight today is _____ kg or _____ lbs
4. My current primary occupation is _____

B. Questions regarding your accident, work and health

Accident

5. The specific or approximate date of my motor vehicle accident was:

6. My vehicle collided with another in the following way (*please tick all responses that apply*):

☐ My vehicle was struck or impacted another vehicle (or other object) on my left side.

☐ My vehicle was struck or impacted another vehicle (or other object), on my right side.

☐ My vehicle was struck or impacted another vehicle (or other object), at the front of my vehicle.

☐ My vehicle was struck or impacted another vehicle (or other object), at the rear of my vehicle.

☐ Other (*Please describe briefly*)_____

Work

7. I have returned to my usual occupation (*Please tick the box beside the answer that most applies to your situation*):

- ☐ Fully
- ☐ Partially: I am working fewer hours or doing modified duties due to injuries related to my motor vehicle accident
- ☐ Not at all: I am off work due to injuries related to my motor vehicle accident
- ☐ Not at all: I am off work for reasons unrelated to my motor vehicle accident
- ☐ Other (Please Describe Briefly)

Current Health

Please think about your health in the past week when answering questions 8-12.

8. My biggest problem related to my car accident is

- ☐ Upper body problem (includes area between shoulder blades, in arm or hand, head, neck or upper back)
- ☐ A lower body problem
- ☐ A generalized problem
- ☐ other _____

9.

a) *Please read the entire list and then write the number one beside the answer that fits best for the following statement.*

“My biggest upper body or generalized problem related to my car accident is:”

- ☐ Vertigo (seems like the room is moving or I am moving) and feeling off balance
- ☐ Dizziness only
- ☐ Collapsing or fainting
- ☐ Feeling anxious and stressed frequently or most of the time
- ☐ Bouts of sudden feelings of anxiousness and or feeling sweaty and or feeling like my heart is beating very fast and or dizziness
- ☐ Feeling sick (nausea)
- ☐ Ringing or other funny noises in my ears
- ☐ Hearing loss
- ☐ Reduced tolerance to noise or light
- ☐ Trouble remembering things
- ☐ Trouble swallowing
- ☐ Changes in ability to speak or communicate
- ☐ Changes in my vision
- ☐ Changes in smell or taste
- ☐ Headaches
- ☐ Jaw or face pain
- ☐ Neck or upper back pain and muscle tension
- ☐ Hand, wrist or arm pain
- ☐ Shoulder pain
- ☐ Numbness or tingling in my neck, upper back, face, hand(s) or arm(s)
- ☐ Arm or hand feels very hot or very cold sometimes or turns funny colours
- ☐ Problems sleeping but not from pain
- ☐ Feeling tired and sleepy
- ☐ Trouble concentrating, thinking
- ☐ My neck feels unstable
- ☐ my shoulder, elbow, wrist, hand, finger or thumb feels unstable
- ☐ nightmares
- ☐ problems with coordination in arms or legs

b)

☐ I only have one upper body or generalized problem related to my accident

or

☐ I have more than one upper body or generalized problem related to my accident

If you have more than one upper body or generalized problem related to your accident, please return to the list in question 9 a. and write the number two beside your second biggest problem.

c) ☐ I only have two upper body or generalized problems related to my accident

If you have more than two upper body or generalized problems related to your accident, please return to the list in question 9a. and write the number three beside your third biggest problem.

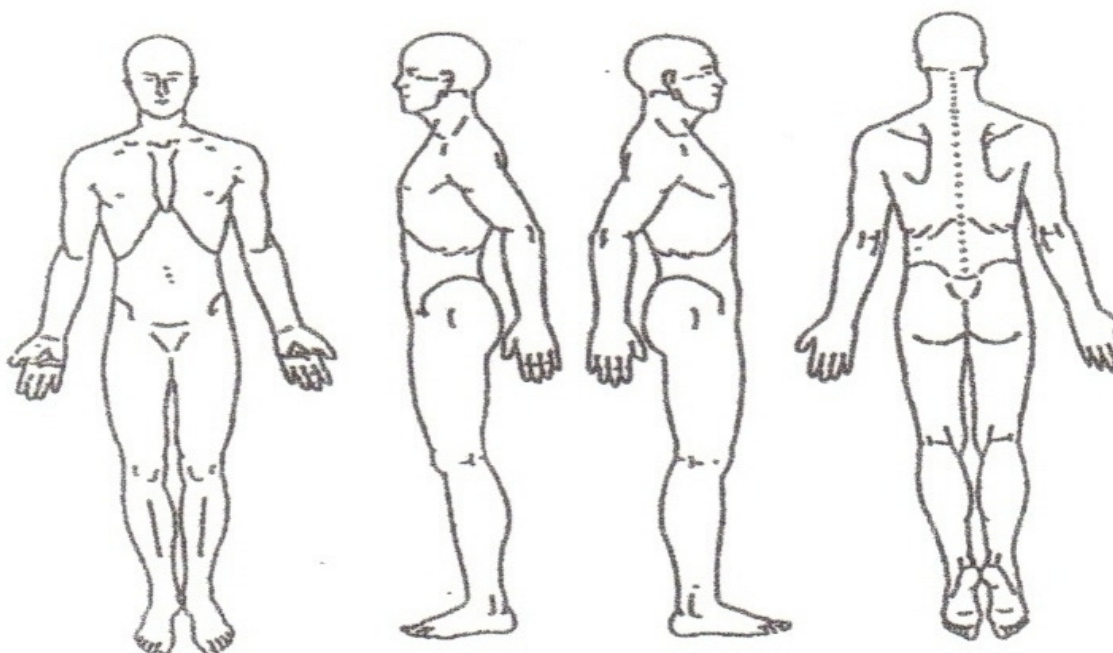
d) *If you have more than three upper body or generalized problems related to your accident please return to the list in question 9a. and place a check mark beside all the problems that apply to you that do not already have a number beside them.*

e) *Please put a line through all the items in the list in question 9.a. that do not apply to you.*

f) *Please check that all items have a number or check mark beside them or a line through them. If not please correct your response.*

10. I have had pain, numbness or other sensations related to my motor vehicle accident in the past week. YES ☐ NO ☐

a) *If yes, colour the symptomatic areas on the body chart provided.*



11. The medications I take for symptoms related to my motor vehicle accident are:

Please include non-prescription medications and natural remedies.

*If you are not taking any medications related to symptoms from your accident,
Write N/A on the first line.*

- a. _____
- b. _____
- c. _____
- d. _____
- e. _____
- f. _____
- g. _____
- h. _____
- i. _____
- j. _____

12. Please list any current major medical problems you have which are unrelated to your motor vehicle accident, e.g. diabetes, cancer, heart disease, rheumatoid arthritis.

- a. _____
- b. _____
- c. _____
- d. _____
- e. _____
- f. _____

Appendix 7.5.2 Neck Disability Index

NECK DISABILITY INDEX (NDI) QUESTIONNAIRE

INSTRUCTIONS: This questionnaire has been designed to give your physiotherapist information as to how your neck pain has affected your ability to manage everyday life. Please mark the ONE answer that applies to you in each of the ten sections. We realize that there may be two possible answers that apply to you, but please mark only the ONE answer that most closely describes your problem.

Pain Intensity

- ☐ I have no pain at the moment
- ☐ The pain is very mild at the moment
- ☐ The pain is moderate at the moment
- ☐ The pain is fairly severe at the moment
- ☐ The pain is very severe at the moment
- ☐ The pain is the worst imaginable at the moment

Personal Care

(Washing, Dressing, etc.)

- ☐ I can look after myself normally without causing extra pain
- ☐ I can look after myself normally, but it causes extra pain
- ☐ It is painful to look after myself and I am slow and careful
- ☐ I need some help but manage most of my personal care
- ☐ I need help every day in most aspects of self care
- ☐ I do not get dressed. I wash with difficulty and stay in bed

Lifting

- ☐ I can lift heavy weights without extra pain
- ☐ I can lift heavy weights, but it gives extra pain
- ☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned for example on a table
- ☐ Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned
- ☐ I can lift very light weights.
- ☐ I cannot lift or carry anything at all

Reading

- ☐ I can read as much as I want with no pain in my neck
- ☐ I can read as much as I want with slight pain in my neck
- ☐ I can read as much as I want with moderate pain in my neck
- ☐ I can't read as much as I want because of moderate pain in my neck
- ☐ I can hardly read at all because of severe pain in my neck
- ☐ I cannot read at all

Headaches

- ☐ I have no headaches at all
- ☐ I have slight headaches which come infrequently
- ☐ I have moderate headaches which come infrequently
- ☐ I have moderate headaches which come frequently
- ☐ I have severe headaches which come frequently
- ☐ I have headaches almost all the time

Concentration

- ☐ I can concentrate fully when I want with no difficulty
- ☐ I can concentrate fully when I want with slight difficulty
- ☐ I have a fair degree of difficulty in concentrating when I want
- ☐ I have a lot of difficulty in concentrating when I want
- ☐ I have a great deal of difficulty in concentrating when I want
- ☐ I cannot concentrate at all

Neck Disability Index Questionnaire

Work

- ☐ I can do as much work as I want
- ☐ I can only do my usual work, but no more
- ☐ I can do most of my usual work, but no more
- ☐ I cannot do my usual work
- ☐ I can hardly do any work at all
- ☐ I can't work at all

Driving

- ☐ I can drive my car without any neck pain
- ☐ I can drive my car as long as I want with slight pain in my neck
- ☐ I can drive my car as long as I want with moderate pain in my neck
- ☐ I can't drive my car as long as I want because of moderate pain in my neck
- ☐ I can hardly drive at all because of severe pain in my neck
- ☐ I can't drive my car at all

Sleeping

- ☐ I have no trouble sleeping
- ☐ My sleep is slightly disturbed (less than 1 hour sleepless)
- ☐ My sleep is mildly disturbed (1-2 hours sleepless)
- ☐ My sleep is moderately disturbed (2-3 hours sleepless)
- ☐ My sleep is greatly disturbed (3-5 hours sleepless)
- ☐ My sleep is completely disturbed (5-7 hours sleepless)

Recreation

- ☐ I am able to engage in all my recreation activities with no neck pain at all
- ☐ I am able to engage in all my recreation activities with some pain in my neck
- ☐ I am able to engage in most, but not all of my usual recreation activities because of pain in my neck
- ☐ I am able to engage in a few of my usual recreation activities because of pain in my neck
- ☐ I can hardly do any recreation activities because of pain in my neck
- ☐ I can't do any recreation activities at all

Please rate the severity of your neck pain by choosing the number below

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
0	1	2	3	4	5	6	7	8	9	10

No pain

Unbearable pain

Appendix 7.5.3 Impact of Events Scale (IES)

On _____ (approximate date) you experienced a motor vehicle accident. Below is a list of comments made by people after stressful life events. Please check each item, indicating how frequently these comments were true for you DURING THE PAST SEVEN DAYS. If they did not occur during that time please mark the 'NOT AT ALL' column.

1. I thought about it when I didn't mean to.	Not at all Rarely Sometimes Often
2. I avoided letting myself get upset when I thought about it or was reminded of it.	Not at all Rarely Sometimes Often
3. I tried to remove it from memory.	Not at all Rarely Sometimes Often
4. I had trouble falling asleep or staying asleep because pictures or thoughts about it came into my mind.	Not at all Rarely Sometimes Often
5. I had waves of strong feelings about it.	Not at all Rarely Sometimes Often
6. I had dreams about it.	Not at all Rarely Sometimes Often
7. I stayed away from reminders about it.	Not at all Rarely Sometimes Often
8. I felt as if it hadn't happened or it wasn't real.	Not at all Rarely Sometimes Often
9. I tried not to talk about it.	Not at all Rarely Sometimes Often
10. Pictures about it popped into my mind.	Not at all Rarely Sometimes Often
11. Other things kept making me think about it.	Not at all Rarely Sometimes Often
12. I was aware that I still had a lot of feelings about it but I didn't deal with them.	Not at all Rarely Sometimes Often
13. I tried not to think about it.	Not at all Rarely Sometimes Often
14. Any reminder brought back feelings about it.	Not at all Rarely Sometimes Often
15. My feelings were kind of numb.	Not at all Rarely Sometimes Often

Appendix 7.5.4 Tampa Scale of Kinesiphobia (TSK)

READ EACH QUESTION AND CIRCLE THE NUMBER THAT BEST CORRESPONDS TO HOW YOU FEEL.

1. Strongly Disagree
2. Somewhat Disagree
3. Somewhat Agree
4. Strongly Agree

- | | |
|---|---------|
| 1. I'm afraid that I might injure myself if I exercise. | 1 2 3 4 |
| 2. If I were to try to overcome it, my pain would increase. | 1 2 3 4 |
| 3. My body is telling me that I have something dangerously wrong. | 1 2 3 4 |
| 4. My pain would probably be relieved if I were to exercise. | 1 2 3 4 |
| 5. People aren't taking my medical condition seriously enough. | 1 2 3 4 |
| 6. My accident has put my body at risk for the rest of my life. | 1 2 3 4 |
| 7. Pain always means I have injured my body. | 1 2 3 4 |
| 8. Just because something aggravates my pain does not mean it is dangerous. | 1 2 3 4 |
| 9. I am afraid that I might injure myself accidentally. | 1 2 3 4 |
| 10. Simply being careful that I do not make any unnecessary a movement is the safest thing that I can do to prevent my pain from worsening. | 1 2 3 4 |
| 11. I wouldn't have this much pain if there weren't something potentially dangerous going on in my body. | 1 2 3 4 |
| 12. Although my condition is painful, I would be better off if I were physically active. | 1 2 3 4 |
| 13. Pain lets me know when to stop exercising so that I don't injure myself. | 1 2 3 4 |
| 14. It's really not safe for a person with a condition like mine to be physically active. | 1 2 3 4 |
| 15. I can't do all the things normal people do because it's too easy for me to get injured. | 1 2 3 4 |
| 16. Even though something is causing me a lot of pain, I don't think it's actually dangerous. | 1 2 3 4 |
| 17. No one should have to exercise when she/he is in pain. | 1 2 3 4 |

Appendix 7.6 WAD Participant Demographics

Table15 Demographics and clinical characteristics of WADII participants; symptoms only listed if experienced in previous week; * ages not included in order to maintain anonymity of participants

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
1.	28	WADIIA CCFT ROM	8.8	Left	5	Full Return	Neck or upper back pain and muscle tension (1) shoulder pain (2), upper limb pain (3), episodic anxiety, nausea, tinnitus, hypoacusia, memory loss, visual disturbance, altered smell/taste, headaches, jaw/facial pain, upper body numbness, fatigue, impaired concentration/thinking	None	MVA related low back pain radiating to legs and knee pain

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
2.	38	WADIIC IES Multimodal Sensitivity	1.4	Rear	6	Fully Returned but occasional days off and shorter days due to pain	Headaches (1), neck or upper back pain and muscle tension (2)	Pain reliever (Tylenol-extra strength), Anti-inflammatory (Naproxen) Combined Narcotic and anti-inflammatory (Advil with codeine)	MVA related low back pain
3.	46	WADII C IES Multimodal sensitivity	1.9	Right side	8	Partial Return	Neck or upper back pain and muscle tension (1), headaches (2), trouble concentrating/thinking (3), feeling anxious and stressed frequently/most of the time, bouts of sudden anxiety, tinnitus, neck feels unstable, arm/hand circulation problems and upper limb pain	Topical anaesthetic, topical anti-inflammatory, oral anti-inflammatory (Advil), muscle relaxant, Pamprin? related to MVA	MVA related thoracic and lumbar pain Major weight gain (post MVA- 70 lbs)

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
4.	64	WADIIC Multimodal Sensitivity	0.9	Rear	6	Partial Return	Neck or upper back pain and muscle tension (1), headaches (2), shoulder pain (3) neck feels unstable, dizziness, anxiety, nausea, memory and other cognitive dysfunction, problems sleeping (not from pain), fatigue,	None	MVA related thoracic pain
5.	60	WADIIB GHQ Cervical PPT CCFT ROM	1.8	Rear	8	Not working due to MVA related injuries	Neck or upper back pain and muscle tension (1), panic attacks (2), sleep disruption/not from pain (3), instability of neck and upper extremity, dizziness, anxiety, nausea, sensitivity to noise or light, impaired memory, impaired communication, other cognitive impairments, visual disturbance, upper limb pain, numbness in upper body, fatigue, impaired coordination in arms or legs	Homeopathic remedy- Causticum (potassium hydrate), anti-inflammatory, analgesic (Tylenol), melatonin, Supplements (Vit. D, E, Calcium, Magnesium)	MVA related thoracic pain

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
6.	22	WADIIB GHQ Cervical PPT CCFT ROM	2.1	rear	3	Fully Returned	Neck or upper back pain and muscle tension (1), shoulder pain (2)	Muscle Relaxant (Roabaxacet Platinum)	MVA related thoracic, lumbar, bilateral hip, bilateral knee pain
7.	22	WADIIB GHQ ROM	15.8	rear	4	Fully Returned	Reduced tolerance to noise or light, neck or upper back pain and muscle tension including past week (2), headaches (3), neck feels unstable, dizziness, nausea, tinnitus, impaired swallowing, upper limb pain, numbness/tingling in upper body, upper limb circulation problems (gets very cold), fatigue, cognitive impairments	None	High Blood Pressure

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
8.	24	WADIIB GHQ Cervical PPT CCFT ROM	1.4	Left	6	Fully returned	Neck or upper back pain and muscle tension (1), shoulder Pain (2), hand /wrist pain (3), headaches, jaw/face pain, upper body dysesthesia, fatigue, cognitive and memory impairments	Anti-inflammatory (Advil, Aspirin)	None
9.	70	WADIIB GHQ Cervical PPT CCFT ROM	15.9	Rear	7	On permanent long term disability due to aggravation of MVA related low back injury in work injury	Neck or upper back pain and muscle tension (1), fibromyalgia (1), shoulder pain (3), cognitive impairments, dizziness, anxiety attacks, nausea, increased sensitivity to noise or light, headaches, jaw or face pain, upper extremity dysesthesia, fatigue, neck feels unstable	MSM, magnesium glycinate, anti-inflammatory (ibuprofen)	MVA related Low back pain

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
10.	64	WADIIC IES CCFT	1	Frontal	7	On LTD due to MVA	Neck or upper back pain and muscle tension (1), shoulder pain (2), problems with coordination in arms or legs (3), neck feels unstable, dizziness, frequent anxiety/stress, anxiety attacks, nightmares, tinnitus, noise or light sensitivity, impaired memory, other cognitive impairments, changes in ability to communicate, visual disturbance, headaches, upper limb pain, upper limb instability, upper body dysesthesia, fatigue	Anti-inflammatories, antidepressant (Wellbutrin), muscle relaxants,	MVA related thoracic, lumbar, right leg pain

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
11.	26	WADIIA Cervical PPT CCFT ROM	2	Front Left	3	Fully Returned	Neck or upper back pain and muscle tension (1), shoulder pain (2), upper body numbness/tingling (3), impaired swallowing, visual changes, headaches, impaired sleep (not from pain), fatigue, feeling of neck instability	None	MVA related thoracic, low back pain radiating to leg
12.	26	WADIIB GHQ-28 Cervical PPT CCFT ROM	0.75	Rear	3	Partial return	Neck or upper back pain and muscle tension (1), cognitive impairments including concentration (2), headaches (3), anxiety attacks, shoulder pain, disturbed sleep/not due to pain	None	MVA related thoracic pain, low back pain

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
13.	58	WADIIA CCFT ROM	6.3	Front	6	Unable to return to Previous occupation) due to MVA; training for new career	Neck or upper back pain and muscle tension, headaches (2), cognitive impairment (3), memory impairment, vertigo, dizziness, tinnitus, light/noise sensitivity, changes in ability to speak/communicate, neck instability	Anti-inflammatory (ibuprofen, pineapple), Muscle relaxants	MVA related thoracic pain
14.	56	WADIIB GHQ-28 CCFT ROM PPT	1.8	Front	8	Working full-time but changed careers due to injuries from MVA	Neck or upper back pain and muscle tension (1), chronic anxiety (2), headaches (3), tinnitus, noise/light sensitivity, memory impairment, visual disturbance, upper limb pain, shoulder pain, upper limb circulatory dysfunction, fatigue, neck instability, nightmares	Anti-inflammatory (Naproxen, Advil) Muscle Relaxants Analgesic (Tylenol)	Asthma, MVA related thoracic and low back pain

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
15.	26	WADIIB GHQ CCFT ROM	8.4	Rear followed by front (pushed forward)	3	Fully Returned	Neck or upper back pain and muscle tension (1), shoulder pain (2), disrupted sleep/not due to pain (3), tinnitus, altered smell/taste, headaches, upper body numbness/tingling, fatigue, upper limb instability, nightmares	None	Hypoglycaemia MVA related thoracic pain
16.	20	WADIIA CCFT ROM	2.8	Rear	1	Fully Returned	Neck or upper back pain and muscle tension (1), headaches (2), nausea (3), shoulder pain, neck instability	Anti-inflammatory (ibuprofen) Muscle relaxant (methocarbamol)	MVA related thoracic pain
17.	46	WADIIC Multimodal Sensitivity	4.8	Rear	7	Training for career change due MVA	Neck or upper back pain and muscle tension (1), upper body numbness/tingling (2), neck instability (3), frequent anxiety, shoulder pain, upper limb pain, cognitive impairments, upper extremity joint instability	Narcotic analgesic (Tylenol 3)	Menopause

WAD Subject	NDI Score (0-100)	Sterling	Time Since MVA (y)	Direction of Impact	Neck Pain (0-10)	Work Status	Upper Body and Generalized Symptoms from MVA	Medications	Comorbidities
18.	30	WADIIA CCFT ROM	18.5	Slid over embankment and rolled	2	Partial Duties due to injuries from MVA	Shoulder instability (1), shoulder pain (2), neck or upper back pain and muscle tension (3), upper limb pain	Antiinflammatory (Ibuprofen)	None
19.	16	WADIIA CCFT ROM	3.3	Rear	2	Fully Returned	Neck or upper back pain and muscle tension (1), headaches (2)	None	Cardiac Arrhythmia

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