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Development and Initial Validation of Novel Multi-Planar Neck Strength Assessment and Neuromuscular Training Protocols

Theo H. Versteegh
The University of Western Ontario

Supervisor
Dr Dave Walton
The University of Western Ontario

Graduate Program in Physical Therapy
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Abstract

Concussions are a serious health concern in today's active society. There are many contributing factors to concussions but one that is starting to draw significant attention is the potential role the neck muscles play in mitigating concussive forces. There is evidence that stronger neck muscles may decrease an individual's concussion risk. In order to fully define this role, an appropriate outcome measure for assessing neck strength is required. Once this is established, methods of training to improve neck strength can be evaluated for their effect on neck strength and subsequently effect on concussion risk. This thesis included three studies. Chapter 2 was a within session and between session test-retest agreement of a novel multi-planar neck-strength and upper kinetic chain assessment protocol using a hand-held dynamometer in a healthy adult population. Chapter 3 examined this protocol to determine its preliminary validity. Due to the lack of an accepted 'gold standard' for neck strength assessment, the validity was examined using three *a priori* hypotheses; face validity, known groups validity and convergent validity using EMG muscle activity. Chapter 4 is a pilot study investigating the effects of a training program using a novel neuromuscular neck-training device that has theoretical rationale on how to improve neck function to decrease concussion risk. This investigation demonstrated the device to be safe and potentially effective at improving axial rotation strength. This study provided promising results to justify further fully powered studies with the device. The final chapter provides a summary of this thesis and provides direction and guidance for future research into further defining the role of the neck muscles in concussion.

Keywords

Multi-planar neck strength assessment, reliability, validity, neck strength, training, neuromuscular training, concussion, injury prevention

Co-Authorship Statement

This thesis contains material from a published manuscript (Chapter 2) and two manuscripts that will be prepared for submission (Chapters 3 and 4). Theo Versteegh was the primary author of all chapters contained in this thesis. All studies contained in this thesis were conceived, designed, analyzed, interpreted and written by the primary author with invaluable input and guidance from David Walton, an assistant Professor in the School of Physical Therapy, Faculty of Health Sciences, Western University. Joy MacDermid, a Professor in the School of Physical Therapy, Faculty of Health Sciences, Western University provided guidance on the design of the research program overall and Chapters 2-4; Jim Dickey, an Associate Professor in the School of Kinesiology, Faculty of Health Sciences, Western University provided guidance in EMG methodology, biomechanics, processing and analysis as well as overall methodological support for Chapters 2-4; Carolyn Emery, Associate Dean (Research), Faculty of Kinesiology, University of Calgary provided input and guidance on proper methodology and analysis for Chapters 2-4; Lisa Fischer, Assistant Professor, Departments of Family Medicine and Faculty of Health Sciences, Western University provided clinical guidance and input for Chapters 2-4. Under the direct supervision of Theo Versteegh, Danielle Beaudet, a Masters of Physical Therapy student at the time of writing provided recruitment, data collection and processing support (Chapter 2); Marla Greenbaum, a Masters of Physical Therapy student at the time of writing provided recruitment, data collection and processing support (Chapter 2); Leah Hellyer, a Masters of Physical Therapy student at the time of writing provided recruitment, data collection and processing support (Chapter 2); Amanda Tritton, a Masters of Physical Therapy student at the time of writing provided recruitment, data collection and processing support (Chapter 2).

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List of Abbreviations

ANOVA – Analysis of variance

AUC – Area under the curve

CC – Comparator cohort

CI – Confidence intervals

E:F – Neck extension strength to flexion strength ratio

EMG – Electromyography

FC – Football cohort

ICC – Intraclass correlation coefficient

kgf – Kilogram-force

MDC – Minimal detectable change

N*m – Newton metre

NFL – National Football League

NMT – Neuromuscular training

RMS – Root mean square

ROC – Receiver operating characteristics curve

RROT or LROT – Right or left axial rotation

RSF or LSF – Right or left side-flexion

RSF/ROT or LSF/ROT – Right or left side-flexion/rotation

SCM – Sternocleidomastoid muscle

SD – Standard deviation

SEM – Standard error of measurement

UFT – Upper fibers of trapezius muscle

1 Introduction

The purpose of this thesis is two fold. The first is to present a new method of assessing neck strength and examine its reliability and validity. The second is to examine the effects of a neuromuscular training device that is consistent with the current state of the literature on how to decrease the risk of concussion through training. This first chapter will provide the background and rationale for this thesis. An overview of neck strength assessment and neck function as it pertains to concussion risk is presented. Training principles to be incorporated into neck strengthening are also described. Lastly, a brief synopsis of thesis chapters 2-5 is provided.

A concussion is defined as “a complex pathophysiological process affecting the brain, induced by biomechanical forces.”^{1(pg1)} These biomechanical forces are multi-planar and most often consist of both linear and angular acceleration.² Unfortunately, concussions are not an uncommon occurrence in the world of sports; an estimated 1.6 to 3.8 million sport and recreation-related concussions occur annually in the United States.³ The majority of preventive measures tend to focus on awareness, education, rule changes and enforcement, fair play, and improvements in equipment design.⁴⁻⁹ Strategies that an athlete or individual can initiate to minimize their own concussion risk are limited.

1.1 Neck strength

One promising area of research in concussion prevention involves the role of the neck muscles in absorbing concussive forces to prevent damage to the brain. In 2014 Collins and colleagues¹⁰ showed in over 6,600 high school student athletes that overall neck strength is a significant predictor of concussion risk. More specifically, for every one-

pound increase in neck strength, a student's odds of concussion drop by 5% (OR = 0.95, 95% CI 0.92 to 0.98).¹⁰ The authors concluded that evaluating neck strength differences may be useful in developing a screening tool for determining an athlete's concussion risk. Although these results are encouraging, a few caveats regarding the outcome measure used in this study need to be addressed.

The primary outcome measure in this study was neck strength assessed via a hand-held tension scale. This method was 'validated' by five athletic therapists, of varying levels of experience, by comparing the results from the device to the results gathered using a hand-held dynamometer, "currently the gold standard of measuring neck strength."^{10(pg317)} Unfortunately, the description of the "gold standard" technique was vague and no reference was given to further describe the technique or support their "gold standard" claim. This is not only a weakness in this study but also a limitation in the current state of the literature. Out of four review papers which investigated various methods of examining neck strength, each investigation concluded that no gold standard is currently available, using hand-held dynamometry or otherwise.¹¹⁻¹⁴

Furthermore, the strength values attained by Collins et al.'s method¹⁰ demonstrated flexion strength to be greater than extension strength. However, in the review of neck strength assessment by Strimpakos¹² it is pointed out that "Neck extensors can produce higher forces than flexion or lateral flexion muscles and this trend can be used as an indicator for valid results."^{12(pg422)} To lend support for this analysis, a sub-sample of studies that evaluated neck strength values in a healthy cohort for flexion and extension are presented in Table 1.1 along with the strength ratio of extension to flexion. This table is by no means exhaustive but rather representative of the studies examined by the four

aforementioned review papers and others that separated young healthy male cohorts for appropriate comparison to this thesis' population of interest.

Finally, the neck strength value used for the study by Collins and colleagues¹⁰ study was a composite score consisting of average flexion, extension, and right and left side-flexion results and did not include assessment of axial rotation strength. There is evidence to suggest that rotational acceleration forces in the transverse plane i.e. axial rotation, are some of the most damaging to the brain.^{15,16} Kleiven and colleagues¹⁵ used finite element modeling of equal magnitudes of rotational acceleration in each of the primary planes of motion to demonstrate that the most strain on the cerebral cortex are caused by axial rotation forces. This postulation is supported by Viano and colleagues,¹⁶ who reconstructed head impacts from National Football League (NFL) games using Hybrid III dummies and matched the head kinematics of known concussion impacts from game film. Using finite analyses, they calculated the head displacement, rotation and neck loads of each impact. From this analysis they concluded most NFL concussions occur from impact to the front of the helmet causing primarily axial rotation.

Eckner and colleagues¹⁷ further demonstrated the potential importance of assessing neck strength along all planes of motion, including axial rotation. Maximum isometric neck strength in each plane of motion was measured in 46 male and female contact sport athletes between the ages of eight and 30. Briefly, a weight drop impulsive force load was then applied to the athlete's head in each plane of motion i.e. flexion, extension, side-flexion and rotation. The authors determined that greater isometric

Table 1.1: Selected isometric neck extension and flexion strength values of healthy male subjects.

Reference	n	Age in years (SD) or range	Extension (E)	Flexion (F)	Ratio E:F
Almosnino et al. ¹⁸ 2010	26	21.6 (2.1)	25.8	15.3	1.69
Chiu et al. ¹⁹ 2002	17	19-39	9.9	9.2	1.08
Eckner et al. ¹⁷ 2014	10	18-30	16.8	13.5	1.24
Geary et al. ²⁰ 2013*	25	19 (1.3)	61.3	35.1	1.75
Jordan et al. ²¹ 1999	10	20-30	13.6	9.3	1.46
Kumar et al. ²² 2001	21	19-29	10.2	7.3	1.40
Lisman et al. ²³ 2012	16	21.6 (2.8)	73.6	40.4	1.82
Mansell et al. ²⁴ 2005	17	19.2 (0.9)	18.1	12.1	1.50
Strimpakos et al. ²⁵ 2004	17	19-37	30.8	23.4	1.32
Suryanarayana et al. ²⁶ 2005	19	18-30	45.1	31.4	1.44
Vasavada et al. ²⁷ 2008	35	25.8 (5.3)	24.9	14.7	1.69
Versteegh et al. ²⁸ 2015*	14	19-37	30.8	19.4	1.59
Cagnie et al. ²⁹ 2007	12	20-29	36.5Nm	23.3Nm	1.57
Garcés et al. ³⁰ 2002	27	20-40	253.2Nm	211.2Nm	1.20
Jordan et al. ²¹ 1999	10	20-30	65.1Nm	36.5Nm	1.78
Peolsson et al. ³¹ 2001	13	25-34	48Nm	21Nm	2.29
Seng et al. ³² 2002	10	22-28	45.3Nm	23.3Nm	1.94
Vasavada et al. ³³ 2001	11	20-42	52Nm	30Nm	1.73

* Indicates hand-held dynamometry, all others fixed-frame (values in kgf or Nm where indicated). Ratio = extension strength/ flexion strength

neck strength in the appropriate plane of motion was independently associated with decreased linear and angular head acceleration in that plane ($r = 0.42$ to $r = 0.66$). Of all strength values and planes tested, maximum isometric axial rotation strength showed the strongest association with decreased linear and angular head accelerations ($r = 0.66$, $p < .01$). These results, along with the conclusions from both Kleiven et al.¹⁵ and Viano et al.¹⁶ suggest the ability to measure axial rotation strength may help further define the role of neck strength in assessing concussion risk.

1.2 Neck function

The presence of neck pain is indicative of a dysfunction in the neck and a lack of optimum functional performance.³⁴⁻³⁶ The presence of headache, in some cases, may also be indicative of neck dysfunction.^{37,38} In a prospective cohort of over 3800 male hockey players aged 11-14, Schneider and colleagues³⁹ showed that pre-season complaints of neck pain was the single highest risk factor for concussion (RR = 1.67, 95% CI 1.15 to 2.41), followed by complaints of headache (RR = 1.47, 95% CI 1.01 to 2.13). While not conclusively causal, this supports the importance of proper neck function in mitigating concussion risk.

Neck dysfunction may also be a source of confounding symptoms that are (mis) diagnosed as concussion. In a prospective cohort study of 15-35 year old male hockey players Hynes and Dickey⁴⁰ determined that there is a strong association between whiplash induced neck injuries and symptoms of concussion. Of 183 players, six received a whiplash injury while seven received a concussion injury. Irrespective of the mechanism of injury, all 13 players reported concussion symptoms *and* whiplash

associated disorder symptoms (WAD classification system, 0 = no complaints to IV = most severe), with symptoms ranging from WAD I to III. More recently, Leddy and colleagues⁴¹ further confirmed this blend of symptomology between concussion and neck dysfunction. A convenience sample of 128 post-concussion disorder (PCD) patients (individuals who remained symptomatic for more than three weeks after sustaining a head injury) were classified as either cervicogenic/vestibular PCD (normal treadmill test, abnormal cervical/vestibular exam) or physiologic PCD (abnormal treadmill test, normal cervical/vestibular exam). The authors found no statistical method that could adequately distinguish the two groups from each other based on self-reported symptoms and thus concluded that symptoms after head injury do not discriminate between concussion and cervicogenic/vestibular injury.

1.3 Stiffness and anticipation

Biomechanical models have demonstrated stiffer necks decrease head acceleration and displacement from impact.^{16,42} Using the system of reconstructed head impacts from NFL games mentioned above, Viano and colleagues¹⁶ developed a head/neck model to determine the effect of neck strength and stiffness on head kinematic responses. By increasing the stiffness of the neck component they were able to substantially reduce the resultant head acceleration and displacement. These authors have shown that even small reductions in the change in head velocity can have a significant effect in decreasing the head injury criterion (HIC), a proxy for concussion risk. Simoneau and colleagues⁴³ showed that in seven healthy subjects neck stiffness can be increased through cervical muscle pre-loading and muscle contraction. Pre-loading the cervical muscles by 8.9 N

caused nearly a 20% decrease in the peak head angular velocity response to an impulse load in either direction of flexion or extension.

The previously discussed study by Eckner and colleagues¹⁷ also demonstrated the effect of anticipatory muscle *contraction* in mitigating peak head acceleration (both angular and linear) from an impulse load. They calculated a significant decrease in linear and angular acceleration of 12.3% and 9.7% respectively when the subjects anticipated the impulse load versus when the load was unanticipated. The authors concluded the ability to anticipate a hit coming and bracing the neck muscles as a means of lowering a player's risk of concussion. This conclusion is synonymous with Mihalik and colleagues⁴⁴ who examined the relationship between collision type and anticipation level using video footage and instrumented helmets in 16 young hockey players. More specifically, in medium-intensity head impacts (defined as 50th -75th percentile of Head Impact Telemetry severity profile (HITsp) – a similar metric as the HIC), players with good anticipation prior to collision had significantly less rotational acceleration (1215 rad/s² 95% CI 1112 to 1327 rad/s²) than players who had no anticipation prior to collision (1466 rad/s² 95% CI 1240 to 1731 rad/s²). Thus also suggesting that bracing for impact by contracting the neck muscles helps lower head acceleration in vivo.

Lastly, Schmidt and colleagues⁴⁵ explored the effects of various muscle characteristics in football players on head kinematic response to weight drop impulse load. They concluded that greater cervical stiffness might reduce an athlete's risk of suffering a concussion. They further concluded that along with stiffness, neuromuscular training focused on enhancing the dynamic muscular response of the cervical muscles might be more effective at mitigating concussion risk. These results suggest that strength,

stiffness and neuromuscular response are all potentially important protective mechanisms to study.

1.4 Neck training

To date, few studies have examined the effects of strength training on the head kinematic and muscular response to impulse loading. Using a pre-test and posttest randomized control group design, Mansell and colleagues²⁴ examined 36 collegiate level soccer players' (17 men, 19 women) head kinematic (head acceleration or displacement), head/ neck stiffness and EMG response (peak activity, muscle activity area and onset latency for sternocleidomastoid (SCM) or upper fibers of trapezius (UFT)) to a weight drop impulse load applied to the head. The intervention group trained for eight weeks on an isotonic resistance-training machine. The training program consisted of three sets of 10 repetitions for each direction of flexion and extension with an intensity ranging from 55% to 70% of the individual's 10-repetition maximum. Although this intensity is lower than what is suggested for maximizing strength development in trained athletes,⁴⁶ the authors still showed modest improvements in flexion strength in the males and females (15%) and in female extension strength (22.5%). After completion of the training program head kinematic, head/ neck stiffness and neck EMG response to the impulse load was re-evaluated and compared to the matched control group. Despite the improvements in neck strength, they found no effects of the training on head kinematic, head/neck stiffness or EMG activity.

Additionally, in a group of 16 college-aged males with previous high-school level football playing experience, Lisman and colleagues²³ examined the effect of a neck

strength training program on head kinematic (acceleration, displacement and time to peak acceleration) and absolute root mean square EMG (rmsEMG) response to a football dummy tackling drill. The eight-week neck strength-training program was characterized by two to three training sessions per week, in which each session consisted of three sets of 10 repetitions in the flexion, extension and right and left side-flexion directions. The exercises were performed on a 4-way neck machine, a similar apparatus to the one used by Mansell et al.²⁴ but, unlike Mansell et al.,²⁴ this training regimen produced more modest results after the eight weeks of training. The only statistically significant improvements were found in extension and left side-flexion of 7% and 8% respectively. Lisman et al. also failed to show a significant effect of the training on either the head kinematic or EMG response to the dummy tackling drill. Both of these studies concluded that traditional resistance type training might not be appropriate for improving head kinematic and neuromuscular responses to sudden head accelerations. These authors,^{23,24} along with Schmidt et al.,⁴⁵ proposed developing programs that incorporate enhancing neuromuscular control, dynamic stabilization and higher-speed or plyometric training i.e. neuromuscular training.

1.5 Neuromuscular training

Several systematic reviews suggest there is strong evidence that neuromuscular training (NMT) is effective at preventing injuries.⁴⁷⁻⁵¹ A recent review and meta-analysis conducted by Emery and colleagues⁴⁷ examined 25 randomized controlled trials (RCTs) and concluded NMT was effective at reducing the risk of lower extremity injuries in active youth under the age of 20 (incidence rate ratio (IRR) = 0.64, 95% CI 0.49 to 0.84). Several factors have been documented to influence the overall effectiveness of a NMT

program in preventing injuries, which includes but is not limited to compliance, duration, frequency and type of training.

Compliance is a significant determining factor for overall effectiveness. Hägglund and colleagues⁵² showed adolescent female soccer players who demonstrated high-compliance to a NMT program reduced their rate of anterior cruciate ligament injury by 88% when compared to controls (IRR = 0.12, 95% CI 0.01 to 0.85). This is in contrast to the low-compliance group who were *not* significantly different than their control counterparts (IRR = 0.77, 95% CI 0.27 to 2.21). Similarly, Steffen and colleagues⁵³ found that in a cohort of young female soccer players, individuals in the high-adherence group (IRR = 0.47, 95% CI 0.15 to 1.43) demonstrated a 72% decrease in the risk of injuries when compared to lower adherence groups (IRR = 1.90, 95% CI 0.88 to 4.09).

Longer duration and greater frequency of NMT is also associated with a lower risk of injury. A meta- and sub-group analysis by Sugimoto and colleagues⁵⁴ showed that two or more NMT session per-week (OR = 0.35, 95% 0.23 to 0.53) tended to reduce injuries more than only one NMT session per-week (OR = 0.62, 95% CI 0.41 to 0.94). This review also showed that in female athletes who complete NMT sessions that are at least 20 minutes in length have a lower risk of ACL injury (Odds ratio (OR) = 0.35, 95% CI 0.23 to 0.53) when compared to athletes who complete sessions lasting less than 20 minutes (OR = 0.61, 95% CI 0.41 to 0.90).

The type of NMT training involved is also influential in determining overall injury prevention effectiveness. In their systematic review, Rössler and colleagues⁵⁵ determined NMT programs that incorporate jumping/ plyometric exercises to be significantly better

in regards to injury prevention than programs that did not (RR = 0.45, 95% CI 0.35 to 0.57 versus RR = 0.74, 95% CI 0.61 to 0.90). It is also important to note that NMT is very different than passive or static stretching. Passive stretching is a technique that has *not* been demonstrated to prevent sport injuries.⁵⁶ Furthermore, it has been demonstrated to *decrease* stiffness^{57,58} and has been shown to *decrease* the rate of force development in muscles.⁵⁹ As research suggests *greater* neck stiffness and *increasing* the rate of force development of the neck muscles to be potentially mitigating factors of head acceleration,^{16,42,60} passive stretching of the neck prior to sport participation should likely be avoided.

Although most studies on the effect of NMT on injury prevention only look at lower extremity injuries, there is some support for its use in the upper extremity as well. Parkkari and colleagues⁶¹ demonstrated a decrease in the risk of upper extremity injury in NMT trained young male conscripts with moderate to high baseline fitness (n = 315) compared to the control cohort (n = 298) (adjusted hazards ratio 0.37, 95% CI 0.14 to 0.99).

1.6 Conclusion

The evidence in the field to date suggests that neck strength plays a role in concussion risk, however in order to fully define this role, an appropriate outcome measure for assessing neck strength is required. The evidence also suggests a NMT program that incorporates high-speed, plyometric type contractions that increase the rate of force development of the neck muscles may reduce the odds of sustaining high-magnitude head impacts associated with concussions in sports.

This thesis proposes to develop an appropriate outcome measure for assessing neck strength in order to allow future research to more fully define the relationship between neck strength and concussion risk. This outcome measure must be safe to administer for both the assessor and the assessed. Second, it must be capable of measuring neck strength along all planes of motion, including axial rotation. Third it should be well described, easy to administer, portable, practical and not dependent on the skill or strength of the assessor. Ideally it should also not require any external equipment for stabilization. Finally, it should be reliable and demonstrate at least preliminary evidence of validity.

The second purpose is to present a method of neck training with a theoretical rationale that is consistent with the state of the literature on how to decrease an individual's concussion risk. This method needs to strengthen the neck muscles along all three planes of movement, specifically axial rotation. It should incorporate plyometric or ballistic type contractions. It should enhance dynamic stabilization and increase the rate of force development of the neck muscles. Most importantly, it should accomplish all of these criteria safely, without the risk of the training method causing a concussion.

Chapter 2 will evaluate the reliability of a neck strength assessment protocol using self-generated resistance and a handheld dynamometer. Chapter 3 will assess the validity of this neck strength assessment protocol. As there is currently no 'gold standard' by which to compare this protocol in order to determine its concurrent validity, three *a priori* hypotheses will be tested instead. Chapter 4 will examine the effects of training with a novel neuromuscular neck-training device on performance on the device and neck strength using the protocol defined in chapters 2 and 3. Secondary analysis will examine concussion incidence in a group of high-concussion risk football players after training on

the device compared to a matched control group and the team average concussion incidence. Chapter 5 will provide a conclusion and discussion of this thesis and explore future research questions and directions.

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2 Evaluating the Reliability of a Novel Neck-Strength Assessment Protocol for Healthy Adults Using Self-Generated Resistance with a Hand-Held Dynamometer

2.1 Introduction

Assessing muscle strength is a fundamental part of patient care for physiotherapists. The value of a reliable tool to assess muscle strength has been emphasized, both to determine functional impairment and to develop appropriate therapeutic interventions. A review of the literature has shown a lack of neck-strength assessment protocols that evaluate side-flexion and rotation along with flexion and extension and that are both portable and reliable.¹ Currently, fixed-frame dynamometry is the most widely recognized method of reliably assessing isometric neck strength. This method uses a large wall or frame-mounted machine with a fixed base, which are expensive and generally impractical for most clinical settings.² In contrast, hand-held dynamometers are portable, relatively inexpensive, and easy to use. Hand-held dynamometry has been shown to be an objective and reliable measure of strength for several different movements of the extremities in healthy adults.³⁻⁶ Normative reference values have also been determined for these various movements. Although previous research has used hand-held dynamometry to assess neck strength, a review article¹ noted a lack of consistency in the methodology and description of the testing procedure and a lack of normative values. The number of articles reporting comprehensive strength measurements in all planes of the neck is also limited. Of particular note is the difficulty in clinical assessment of neck rotation strength,⁷ which has traditionally been limited to clinically inaccessible lab-based measurement equipment.

One of the challenges of using hand-held dynamometry to assess muscle strength is that results are influenced by the strength of the tester, which may compromise reliability.⁸ If the tester is significantly weaker than the person being tested, the results will only be as high as the force the tester is capable of generating; even if the tester is able to generate sufficient resistance, the stronger the person being tested, the more difficult it becomes for the tester to generate this resistance along the proper vector in a consistent and safe manner, which further decreases the reliability of the results. A person may also be apprehensive about providing full resistance against someone pushing on the side of his or her head.

Our study therefore provides a standardized and functional isometric strength-testing protocol that allows assessment of strength in all planes of the neck, including rotation, using self-generated resistance and a hand-held dynamometer. Given that the resistance is self-generated through the upper kinetic chain (including the shoulder, elbow, wrist, and hand), the test inherently assesses the neck up to the strength limit of the upper kinetic chain. We believe that simultaneous functional assessment of strength about the neck and upper kinetic chain could function as a useful clinical evaluation for people with neck pain and may have potential as a prognostic tool after neck injuries.

The purpose of this study is to evaluate the within-session (10 min) and between-session (6–8 days) test–retest agreement of a novel neck-strength and upper kinetic chain assessment protocol using a hand-held dynamometer in a healthy adult population.

2.2 Methods

2.2.1 Participants

Participants were recruited for this study from the Health and Rehabilitation Sciences programme and the Master of Physical Therapy programme at Western University, as well as from the university community through word of mouth and electronic recruitment (letter of information posting on a Facebook class page; class group email). Volunteers were eligible for inclusion if they were healthy adults aged between 18 and 60 years; able to speak and understand English at a conversational level; free of neck, shoulder, elbow, and wrist pain (self-reported); and able to pass the cervical screening protocol (see Appendix A) with no positive results.

Potential participants were excluded if they had reports of neck pain in the past three months for which they had sought treatment; any history of previous neck surgeries or rheumatoid conditions; known neck instabilities; any current neck pain, whether actively receiving treatment or not; or any current report of injury or pain in the shoulder, elbow, wrist, or temporomandibular joints. After screening, 30 of 32 consecutive participants were included in the study, for a total of 14 men and 16 women aged 19 to 37 years (see Table 2.1). Informed and documented consent was obtained from all participants. The project was approved by the Western University Research Ethics Board for Health Sciences Research Involving Human Subjects.

Table 2.1: Participant characteristics

Sex	n	Mean (SD) age, y	Age Range y
Men	14	25.29 (5.41)	19-37
Women	16	23.94 (1.29)	23-28

2.2.2 Testing protocol

After providing written informed consent, potentially eligible participants were screened by a group of four physiotherapy student examiners (in their 2nd year of the MPT programme), who used a screening protocol to identify any gross cervical dysfunction (decreased active range of motion in any of the three planes of movement, pain during the four quadrants combined planes test, pain with Spurling's cervical compression test).⁹ Participants with a negative screening protocol—that is, those who had grossly good neck health and no exclusion criteria reported—proceeded to perform a standardized strength-testing protocol under the guidance of one of the physiotherapy student examiners (see Appendix A). Because each participant provided his or her own resistance to produce the test values recorded, the four physiotherapy student examiners who administered the protocol were considered to be interchangeable. A standardized, calibrated digital hand-held dynamometer (MicroFET 2TM force gauge, Hoggan Health Industries, Salt Lake City, Utah) was used to evaluate maximum force generated in kilogram-force (kgf) for each plane. The MicroFET 2TM is a common instrument in physiotherapy clinics and ergonomic assessments and has been shown to be valid for muscle force measurement in other joints, including the shoulder, hip, and knee.³⁻⁶ It

consists of a plastic unit housing a force gauge and a soft, cushioned pad that is applied to the long bone of the joint to be tested, as shown in Figure 2.1.

To measure neck strength, participants were seated comfortably on a stool with their feet flat on the floor. They sat with no back or arm rests to prevent bracing the trunk against a chair. One of the four physiotherapy students then guided each participant through the testing procedure. For calibration purposes, the isometric peak force voluntarily and maximally generated with hands in front of the body and palms together during horizontal adduction was recorded (see Figure 2.2A); this value was used to determine the maximum force the participant could generate with the upper extremities and to ensure that he or she had the ability to generate sufficient force to overcome the tested neck movements. After a 3-minute rest, isometric neck strength was tested in eight positions: forward flexion (with resistance applied to the forehead with both hands); extension (with resistance applied with both hands to the occiput); right and left side-flexion (with resistance applied with the ipsilateral hand just above the ear); right and left side-flexion and rotation (with resistance applied with the ipsilateral hand to the temple); and right and left pure rotation (with resistance applied with the ipsilateral hand along the jaw near the chin with jaw clenched), as shown in Figures 2.2B–2.2F (see also Appendix A).



Figure 2.1: MicroFET 2™ dynamometer

All test positions were performed with the neck in neutral; proper positioning was augmented by the use of a mirror. In each “make” test position, the participants were instructed to build up to their maximum cervical muscle force over three seconds, maintaining the static neck position (a “make” test is an isometric strength test in which the tester matches the maximum resistance produced by the testee, maintaining the length of the muscle, and a “break” test is an eccentric test in which the tester exceeds the maximum resistance produced by the testee and causes lengthening of the muscle). The peak force produced in Trial 1 for each test position was recorded. Participants could stop the test at any point during the assessment and were instructed to stop should any pain or dizziness arise. On completing the protocol, participants rested comfortably in a supportive chair for 10 minutes. The neck upper-quadrant protocol was then repeated in all test positions (Trial 2) to evaluate intra-session reliability. This initial visit took approximately 25–30 minutes to complete, including screening and two trials of the

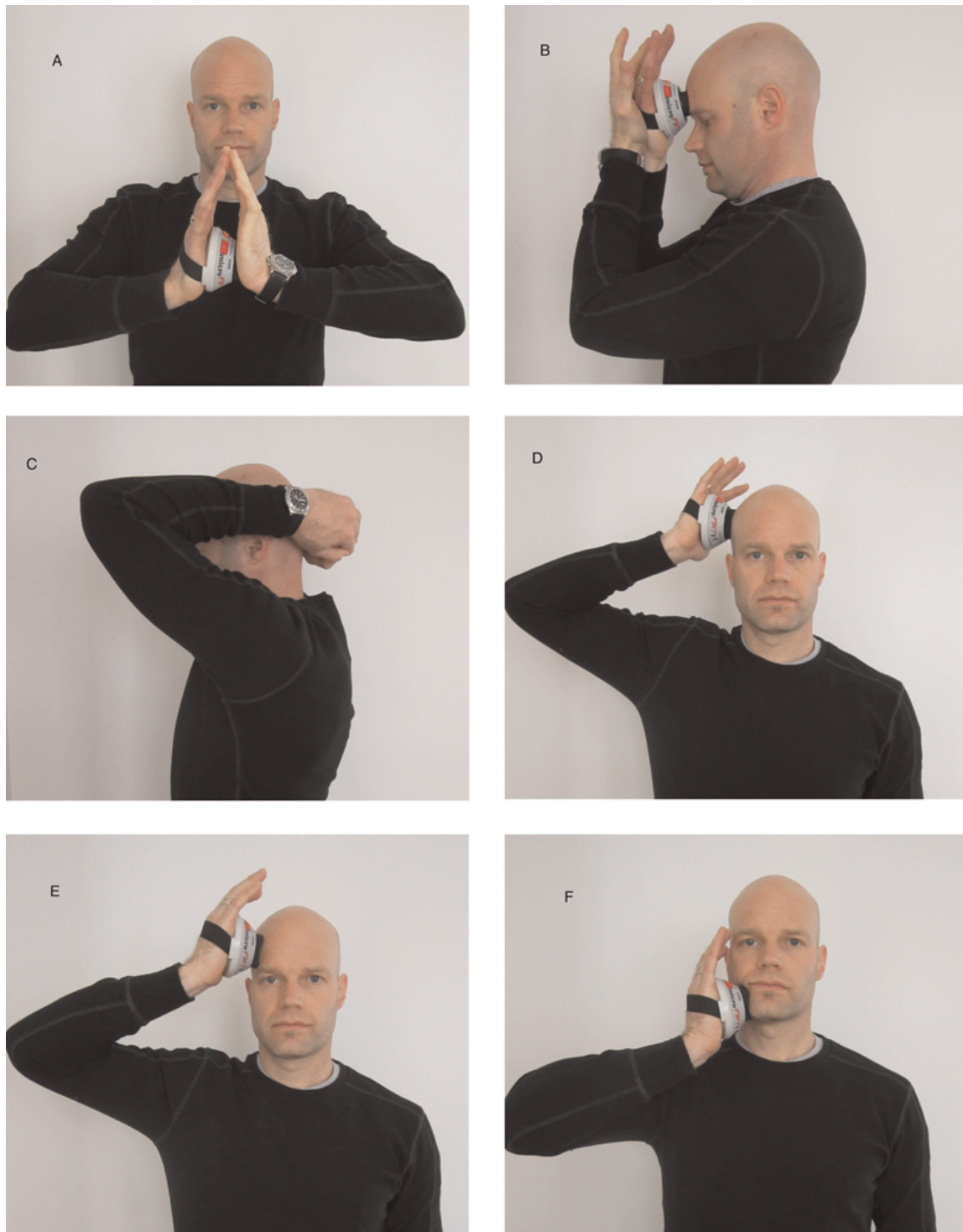


Figure 2.2: Test positions: Calibration (A), forward flexion (B), extension (C), side-flexion (D), side-flexion with rotation (E), axial rotation (F).

strength-testing protocol. Finally, participants returned to the lab after 6–8 days for a second visit to determine inter-session reliability. This second visit was no longer than 10 minutes and consisted of a single trial using the same data-collection process as in the first testing session (Trial 3).

2.2.3 Data analysis

The statistic of interest was the intra-class correlation coefficient type 2,1 (ICC [2,1], absolute). We chose this statistic because it assumes the same group of raters (participants themselves) randomly sampled from the population of possible raters (random effects) and allows for generalizability beyond this study for other participants using themselves as raters. For clinical and research purposes,¹⁰ we expected an ICC (2,1), absolute, of at least 0.8, with 95% confidence that the true value is greater than 0.4. Using these values and a formula presented by Walter and colleagues,¹¹ we calculated that a sample size of 27 would provide 80% power for detecting a true difference between 0.8 and 0.4 where one exists. Therefore, we set a target sample size of 30 to ensure sufficient power for our study. To determine the level of reliability, we adapted the scheme previously reported by Meyers and Blesh,¹² who defined the degrees of reliability based on ICC (2,1), absolute, values as follows: 0.90–0.99, high reliability; 0.80–0.89, good reliability; 0.70–0.79, fair reliability; and ≤ 0.69 , poor reliability.

We also calculated the standard error of measurement (SEM) and the minimal detectable change (MDC). The SEM is used to determine the confidence level around an observed score within which the true score lies; a 95% CI around an observed score is ± 2 SEM.

The MDC is the minimum change in score that must be observed before one can be 95%

confident that a true change has occurred. Bland–Altman plots with 95% limits of agreement were produced for the various test positions across trials (Appendix B).

2.3 Results

All participants completed the full test procedure; none reported experiencing any discomfort during or after testing.

As reported in Tables 2.2 and 2.3, the SEM with 95% CI for the various test positions ranged from 0.96 to 1.71 kgf for Trial 1 and Trial 2 (intra-session reliability) and from 1.29 to 2.04 kgf for Trial 1 and Trial 3 (inter-session reliability). The MDC ranged from 2.66 to 4.72 kgf between Trial 1 and Trial 2 and from 3.38 to 5.64 kgf between Trial 2 and Trial 3. ICCs and 95% CIs for all isometric neck strength measurements (five test positions) for intra-session and inter-session are presented in Tables 2.2 and 2.3, respectively. In this study, ICCs ranged from 0.94 to 0.97 for all tested directions for Trial 1 to Trial 2 (ICC [2,1], absolute), demonstrating that intra-session test–retest reliability was high. The ICC values ranged from 0.87 to 0.95 for all tested directions for Trial 1 to Trial 3 (ICC [2,1], absolute), indicating that inter-session reliability was good to high.

Table 2.2: Intra-session Retest Reliability of Neck Strength Using a Handheld Dynamometer in a Healthy Population

Test Positions	Mean (SD) Trial 1 Test Score, kgf	Mean (SD) Trial 2 Test Score, kgf	Mean Difference*	SEM	MDC	ICC (95% CI)
Forward Flexion	14.20 (6.52)	14.71 (5.91)	0.51	1.13	3.13	0.97 (0.93 to 0.98)
Extension	23.72 (9.10)	24.02 (9.83)	0.30	1.71	4.72	0.97 (0.93 to 0.98)
Pure Side-flexion (L)	14.86 (6.39)	14.91 (6.25)	0.05	1.11	3.07	0.97 (0.93 to 0.99)
Pure Side-flexion (R)	14.84 (6.58)	15.03 (6.47)	0.19	1.32	3.65	0.96 (0.91 to 0.98)
Side-flexion with Rotation (L)	10.75 (4.32)	11.54 (4.67)	0.79	1.14	3.17	0.94 (0.83 to 0.97)
Side-flexion with Rotation (R)	11.39 (4.80)	11.60 (4.76)	0.20	0.96	2.66	0.96 (0.92 to 0.98)
Pure Rotation (L)	12.60 (5.22)	12.92 (5.15)	0.32	1.28	3.54	0.94 (0.87 to 0.97)
Pure Rotation (R)	12.60 (5.87)	12.99 (5.46)	0.39	1.31	3.64	0.95 (0.89 to 0.97)

*Mean difference = trial 2 minus trial 1 strength score. kgf = kilogram-force, SEM = standard error of measurement, MDC = minimal detectable change, ICC = intra-class correlation coefficient (2,1), L = left, R = right.

Table 2.3: Inter-session Retest Reliability of Neck Strength Using a Handheld Dynamometer in a Healthy Population

Test Positions	Mean (SD) Trial 1 Test Score, kgf	Mean (SD) Trial 3 Test Score, kgf	Mean Difference*	SEM	MDC	ICC (95% CI)
Forward Flexion	14.20 (6.52)	15.63 (6.60)	1.43	1.86	5.17	0.92 (0.77 to 0.97)
Extension	23.72 (9.10)	24.81 (8.76)	1.08	2.04	5.64	0.95 (0.88 to 0.97)
Pure Side-flexion (L)	14.86 (6.39)	15.66 (6.21)	0.80	1.43	3.38	0.95 (0.89 to 0.98)
Pure Side-flexion (R)	14.84 (6.58)	15.54 (6.28)	0.70	1.47	4.08	0.95 (0.90 to 0.98)
Side-flexion with Rotation (L)	10.75 (4.32)	12.07 (4.89)	1.32	1.55	4.29	0.90 (0.61 to 0.97)
Side-flexion with Rotation (R)	11.39 (4.80)	12.16 (4.86)	0.77	1.29	3.57	0.93 (0.85 to 0.97)
Pure Rotation (L)	12.60 (5.22)	13.56 (5.48)	0.97	1.98	5.48	0.87 (0.74 to 0.94)
Pure Rotation (R)	12.60 (5.87)	13.67 (5.39)	1.08	1.76	4.88	0.91 (0.79 to 0.96)

* Mean difference = trial 3 minus trial 1 strength score. kgf = kilogram-force, SEM = standard error of measurement, MDC = minimal detectable change, ICC = intra-class correlation coefficient (2,1), L = left, R = right

Table 2.4: Mean strength values by sex of trial 1.

Test positions	Mean strength (95% CI), kgf		Strength values for women as % of strength values for men
	Men	Women	
Forward Flexion	19.4 (16.0 to 22.7)	9.7 (8.2 to 11.2)	50.2%
Extension	30.8 (25.8 to 35.7)	17.7 (15.9 to 19.5)	57.5%
Side-flexion L	20.2 (17.3 to 23.0)	10.2 (8.7 to 11.8)	50.7%
Side-flexion R	20.0 (16.5 to 23.6)	10.3 (9.2 to 11.5)	51.5%
Side-flexion/Rotation L	14.3 (12.3 to 16.3)	7.7 (6.6 to 8.8)	54.1%
Side-flexion/Rotation R	15.0 (12.4 to 17.6)	8.3 (7.1 to 9.4)	55.2%
Pure Rotation L	15.9 (12.9 to 19.0)	9.7 (8.0 to 11.4)	61.1%
Pure Rotation R	16.4 (12.9 to 19.0)	9.3 (7.7 to 10.9)	56.8%
Ratio Extension to Flexion strength	1.56 (1.37 to 1.82)	1.82 (1.61 to 2.08)	

kgf = kilogram-force, L = left, R = right

Average neck strength in Trial 1 ranged from 14.3 to 30.8 kgf for men and from 7.7 to 17.7 kgf for women; women's mean strength ranged from 50.2% to 61.1% of men's. The mean extension-to-flexion ratio in Trial 1 was 1.56 for men and 1.82 for women (see Table 2.4). Although Bland–Altman plots are best used to compare different measurement tools, they can also serve to provide a visual description of the error and variability existing in the same measurement tool at different assessment times. This visual description can be used to qualitatively assess the reliability across the full spectrum of strength values. (see Appendix B).

2.4 Discussion

Our results are consistent with reliability findings from studies using large fixed-frame dynamometers to assess isometric neck strength.¹³⁻¹⁶ For instance, Peolsson and Öberg¹³ examined the intra- and inter-tester reliability of isometric neck strength in 30 healthy participants using a David Back Clinic (DBC 140), a large fixed-frame dynamometer, and found high ICCs (ranging from 0.85 to 0.97) for the tested movements of flexion, extension, and lateral flexion. Chiu and Lo¹⁴ also studied the reliability of isometric neck strength using another large fixed-frame dynamometer, the Multi Cervical Rehabilitation Unit. Their results demonstrated that intra-session test–retest reliability was high for all tested positions of neck flexion (ICC = 0.98), neck extension (ICC = 0.98), left side-flexion (ICC = 0.97), and right side-flexion (ICC = 0.95), all values very similar to those found in our study (flexion = 0.97, extension = 0.97, left side-flexion = 0.97, right side-flexion = 0.96). Comparing our findings with those of Peolsson and Öberg¹³ and Chiu and Lo¹⁴ illustrates that the same level of reliability achieved with large, expensive fixed-frame dynamometry can be achieved using the protocol presented here and the more cost-effective MicroFET 2™.

Although evaluating validity was not a goal of our study, it is notable that we found ratios of extension to flexion strength and comparative strength of men and women that are in line with those found in studies using fixed-frame dynamometry. Using various fixed-frame dynamometry systems, prior studies have found women to be 40%–70%^{7,13,15-17} as strong as men; our study found a range of 50.2%–57.5% for the same movements. In those fixed-frame dynamometry studies that reported the extension-to-flexion ratio, values ranged from 1.28 to 2.38; our study found ratios of 1.82 for women and 1.56 for

men.^{7,13,15-17} Although the values in our study are consistent with those of fixed-frame dynamometry, further studies are needed to formally test the validity of the protocol presented here.

Our protocol avoids a known shortfall of using hand-held dynamometry—the influence of the tester’s strength on the reliability of the test⁸—by having the person being tested provide the resistance. It has also been suggested that measuring neck strength using a break test in people with neck pain is difficult because participants fear evoking pain during the assessment.¹ Our study suggests that assessing neck strength using a closed-kinetic-chain make test is likely to reduce participants’ fears during maximal strength testing because the participant’s own hand is providing the resistance to neck movement. This consideration will be especially important when assessing individuals with neck dysfunction. Our protocol allows participants to stop quickly at any time if they experience pain or discomfort without first informing the therapist, which makes this test inherently safer and easier to administer.

2.4.1 Limitations

Our study has several limitations. First, our convenience sample of 30 participants had a very narrow age range (19–37 years for men, and only 23–28 years for women); future studies should include a sample with a larger age range. Second, the study assessed a healthy cohort of participants, which limits its applicability to a population with pathology. We intend to continue collecting normative values for comparison purposes in future clinical studies. Furthermore, future directions will investigate this protocol as a meaningful evaluation procedure for people with neck pain and as a prognostic tool after

neck injuries.

The proposed assessment protocol also has some limitations. To perform the test, the participant must have sufficient range of motion of the shoulder, elbow, and wrist; the protocol cannot be used effectively if any of these are lacking. The participant must also be able to generate sufficient force to overcome the tested neck movement. This limitation is addressed by having participants perform a calibration test consisting of compressing the dynamometer between their two hands, without interlocking their fingers, in front of their head. For example, if the participant is able to generate 50 kgf for the calibration test and only 18 kgf as a maximum for the side-flexion and rotation components, then it is arguably safe to say that the strength of the side-flexion or rotation movement is the value found with that test. If, however, the calibration value is 18 kgf and the side-flexion and or rotation test also measures approximately 18 kgf, then it is possible that the maximum force of those movements was not determined because the participant may not have been able to generate enough force to overcome his or her own neck strength.

2.5 Conclusion

Our study provides a standardized protocol for assessing neck strength in all planes using a MicroFET 2TM. The results suggest that all five test positions of the neck and upper-quadrant strength assessment procedure can be performed using hand-held dynamometry with good to high reliability. Moreover, self-generated resistance using a MicroFET 2TM to measure neck strength could be a reliable evaluation procedure for a healthy population.

2.6 Key Messages

2.6.1.1 *What is already known on this topic*

Reliable methods of assessing neck strength currently exist, but these methods have several limitations. Many of them require large, expensive fixed-frame dynamometry systems that are not practical for use in most clinics. Protocols that use portable hand-held dynamometry lack standardization and depend on the therapist's being stronger than the patient. They also commonly rely on break tests that can cause apprehension, pain, and safety concerns for the participant or patient.

2.6.1.2 *What this study adds*

This study describes a novel method for assessing neck strength that is safe, reliable, cost effective, and independent of therapist strength. It also provides a standardized method for assessing all neck movements, including flexion, extension, side-flexion, and rotation.

2.7 References

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3 Examining the validity of a novel neck strength assessment tool

3.1 Introduction

It is estimated that there are up to 3.8 million sports and recreation-related concussions each year in the United States.¹ Given this high incidence, healthcare workers are looking for simple and valid methods of assessment and screening that may help establish individuals' concussion risk.² A pilot study assessing anthropometric measurements of over 6,600 high school athletes suggests that neck flexion, extension and lateral flexion strength may be a protective factor in reducing concussion risk.³ Specifically, for every one-pound increase in neck strength, odds of concussion decreased by 5%. Since axial rotation strength was not measured, it is not known if it is also associated with concussion risk. Given that concussions are caused by multi-planar linear and rotation forces,⁴⁻⁶ it may be of benefit to measure neck strength in all primary planes of motion (flexion/extension, lateral flexion and axial rotation).^{7,8} A systematic review by Dvir and Prushansky⁹ found only 6 of 16 methods of assessing neck strength assessed axial rotation strength. Strimpakos¹⁰ has suggested axial rotation strength is not frequently included because of the practical difficulty in assessing this movement. The methods that do exist are neither portable nor practical. An accurate and reliable means of assessing neck strength that includes all three primary planes of movement may help further define the role of the neck muscles in concussion risk, and provide additional guidance for prevention and screening.

There have been a number of studies that have examined isometric neck strength that have led to four review papers evaluating these approaches.⁹⁻¹² Each of these four reviews concluded that there is currently no gold standard for neck strength assessment. Most studies used a form of fixed frame dynamometry to assess neck strength. These devices are large and may be cost-prohibitive for most smaller or non-specialized clinics. Other approaches used custom-built machines that are not widely available. Problematically, the use of different measurement apparatuses has led to vastly different normative strength values for samples from similar populations, in some cases differing by 10-fold between studies.^{13,14} Even the ratios of extension strength to flexion strength (E:F) within these different studies range from values indicating extension is 10% to over 100% greater than flexion.^{13,15} Inconsistent methods and results make comparisons between studies and defining translatable normative strength values difficult. However, Strimpakos¹⁰ points out that neck extensors can produce higher forces than flexion or lateral flexion muscles and that this trend can be used as an indicator of valid results. It is also expected that strength values from the right and left side should be symmetrical (i.e. side-flexion, rotation).⁹

Other studies have used operator-applied hand-held dynamometry and portable strain gauges as a method of assessing neck strength.¹⁶⁻¹⁹ However, these approaches also have limitations. For example, Wikholm and Bohannon²⁰ found that inter-rater reliability was influenced by the strength difference between the examiner and the subject; weaker examiners demonstrated less consistency in scores. This becomes particularly challenging for care providers when assessing high level contact sport athletes.

Since these reviews, a method of assessing neck strength using a hand-held dynamometer has been presented that addresses these shortcomings. Versteegh and colleagues²¹ proposed a method of evaluating neck strength using a hand-held dynamometer and self-generated resistance by the subject. By having the subjects generate their own resistance, it can be argued that there is an element of added safety insofar as resistance applied to the neck can be rapidly modulated. This method also eliminates the need for external stabilization as the subjects' use their own hand and arm or arms to generate the resistance, which should naturally engage the torso for stability. As a result, this test is probably best conceptualized as an evaluation of overall kinetic chain activity influenced most strongly by neck strength. Notably, this method also provides an easy means of assessing neck rotation strength with a hand-held device, which to our knowledge has not been previously examined.

Although this method of neck assessment has shown good reliability (Intraclass correlation coefficient (ICC) ranged from 0.87-0.97),²¹ no formal attempt to date has been made to evaluate the validity of the protocol. Because there is no gold standard to compare the results of this method, true concurrent criterion-based validity cannot be achieved.²² In the absence of a gold standard, an argument for its construct validity will be made through instrumentation accuracy as well as face validity, known groups discriminative validity and convergent validity of EMG analysis through a series of *a priori* serial hypotheses.

3.1.1 Hypotheses

1. Face validity: The E:F strength ratio obtained from this new testing method should be greater than 1 and within the range of ratios obtained from other tools reported in the literature.¹⁰ In accordance with published literature, extension strength should also be significantly stronger than each of the unilateral strength tests. Strength values for side-flexion, side-flexion/rotation and axial rotation should not be significantly different between the right and left sides in healthy subjects.⁹
2. Known Groups validity: A sample of male football players who train with a neck strengthening machine as part of their standard training protocol will show significantly higher peak isometric neck strength on the new protocol than will a group of age- and sex-matched non-football players who do not routinely train neck strength. When ability to discriminate between the two groups (sensitivity vs. 1-specificity) is plotted using a Receiver Operating Characteristic (ROC) curve, the area under the curve should be statistically greater than parity (0.5) for all directions tested.
3. Convergent Validity: the peak EMG activity of the upper fibers of trapezius (UFT) and sternocleidomastoid (SCM) muscles during the neck exertions will follow a predictable pattern based on the known function of the muscle and the movement tested. The expected pattern should reveal statistically significant between-muscle group relationships, as presented in Table 3.1.

Table 3.1: Anticipated pattern of EMG activity by direction

Direction	Hypothesized pattern of Peak EMG	
	UFT	SCM
Flexion	R = L	< R = L
Extension	R = L	> R = L
RSF	R > L	R > L
LSF	L > R	L > R
RROT	R > L	L > R
LROT	L > R	R > L

UFT = upper fibers of trapezius, SCM = sternocleidomastoid, R = right side muscle, L = left side muscle, RSF=right side-flexion, LSF = left side-flexion, RROT = right rotation, LROT = left rotation.

3.2 Methods

This was a cross-sectional observational study of two known groups.

3.2.1 Participants

Participants were recruited for the football cohort (FC) from the spring camp roster of the Western University Varsity Football Team. The age and sex-matched comparator cohort (CC) were drawn from the Health and Rehabilitation Sciences program and the university community at Western University, London, Ontario, Canada. Volunteers for the FC were eligible if they were healthy members of the varsity football

team aged between 18 and 25 years. The CC subjects were also healthy male university students aged between 18 and 25 years but not members of the football team. They were recruited through word of mouth and electronic recruitment. All subjects were either medically cleared for participation in full contact football by the team's medical staff (FC) or a member of the research team cleared them using a standardized protocol as performed within other studies (CC).²¹ Subjects were excluded if they had reports of neck pain in the past three months for which they had sought treatment; any history of previous neck surgeries or rheumatoid conditions; known neck instabilities; any current neck pain, whether actively receiving treatment or not; or any current report of injury or pain in the shoulder, elbow, wrist, or temporomandibular joints (self reported).

Anticipating a large effect size²³ of 0.8 with 80% power and an alpha rate of .05 a minimum of 32 subjects was calculated to determine face validity in the FC using G*Power (ver 3.1.9.2).²⁴ Effect sizes as large as 2.8 are found between strength trained and non-strength trained males.²⁵ Therefore a conservative effect size of 1.0 was chosen to ensure this study was sufficiently powered to determine whether a difference in strength existed between the FC and CC. Knowing the size of the FC determined a minimum of 10 subjects was needed for the CC. After screening, 38 subjects were selected for FC and 12 male subjects were selected for inclusion in CC. Formal written informed consent was obtained from all subjects prior to participation in the study. The Western University Research Ethics Board approved the project for Health Sciences Research Involving Human Subjects.

3.2.2 Testing protocol

3.2.2.1 *Preparation:*

For FC, age, playing position and concussion history were collected along with their height, weight and years on the team. Neck girth was measured in centimeters using a flexible measuring tape just below the thyroid cartilage. For CC, sex and age were collected.

3.2.2.2 EMG recording methods: (*FC only*):

The skin was prepared using disposable alcohol wipes. Using a bipolar configuration, 40.8 x 34 mm Ag/AgCl round disposable surface electrodes (Ambu® BlueSensor M) were placed on the right and left SCM and UFT. For SCM the participant was asked to rotate their head all the way to one side (e.g. left). The opposite SCM (e.g. right) was then palpated and two surface electrodes were placed on the middle of the muscle belly approximately 2 cm apart.²⁶ A third reference electrode was placed on the middle portion of the clavicle. For the upper fibers of trapezius the two surface electrodes were placed midway between the C7 spinous process and the lateral tip of the acromion 2 cm apart.²⁷ The reference electrodes were placed on the C7 and T2 spinous processes. Surface electrode leads were then connected to the corresponding wireless EMG sensor (Shimmer Sensors Inc®, Dublin, Ireland) that sampled at a rate of 512 Hz. The Shimmer Sensor has a DC input impedance of 1000 megaohms, a common mode rejection ratio of > 105 dB at 60 Hz, a signal-to-noise ratio (SNR) of 107 dB and programmable gain of 6. The signal was passed to a laptop computer through Bluetooth wireless communication for capture and to allow real-time monitoring of EMG activity for signal quality.

3.2.2.3 Strength Recording Method:

Maximum isometric strength was measured using a MicroFET 2™ hand-held dynamometer (Hogan Industries, Salt Lake City USA). This device has a high intra-tester reliability for the testing protocol used (intra-session ICC = 0.94-0.97, inter-session ICC = 0.87-0.95)²¹ and has a reported accuracy rating to within 0.05 kgf²⁸ with an effective range of 0.05 to 150 kgf.

3.2.2.4 Testing Protocol:

Each subject was guided through a maximum isometric neck strength testing protocol using self-generated resistance as previously described.²¹ The subject was seated comfortably on a stool facing a mirror and instructed to keep the head inline with the body during each test position. The test involved maximally pressing both hands into the MicroFET 2™ held just in front of their head (see Figure 3.1A). This score was used for calibration purposes. The calibration is used as a gross estimate of the amount of resistance that the individual is able to generate with each arm for unilateral testing (removing the effect of the neck). So long as this calibration score is greater than each of the unilateral test positions it is assumed the weakest link in the kinetic chain is the neck and not the arm applying the resistance. The subjects were then led through the other eight test positions: flexion, extension, right side-flexion (RSF), left side-flexion (LSF), right side-flexion/ rotation (RSF/ROT), left side-flexion/ rotation (LSF/ROT), right rotation (RROT) and finally left rotation (LROT) (Figure 3.1). For each test position the subject was instructed to build up to their maximum pressure, hold for three seconds, and then relax all the while maintaining the static neck position. The evaluator provided

similar vocal motivation to each subject as per Versteegh and colleagues.²¹ Each participant was blinded to the planned comparison between the FC and CC. One subject in the FC who had their wisdom teeth removed one week prior to testing did not participate in the pure rotation assessment (all analysis involving rotation $n = 37$). EMG activity was recorded using proprietary Multi-Shimmer Sync[®] software (v2.11, Dublin Ireland).

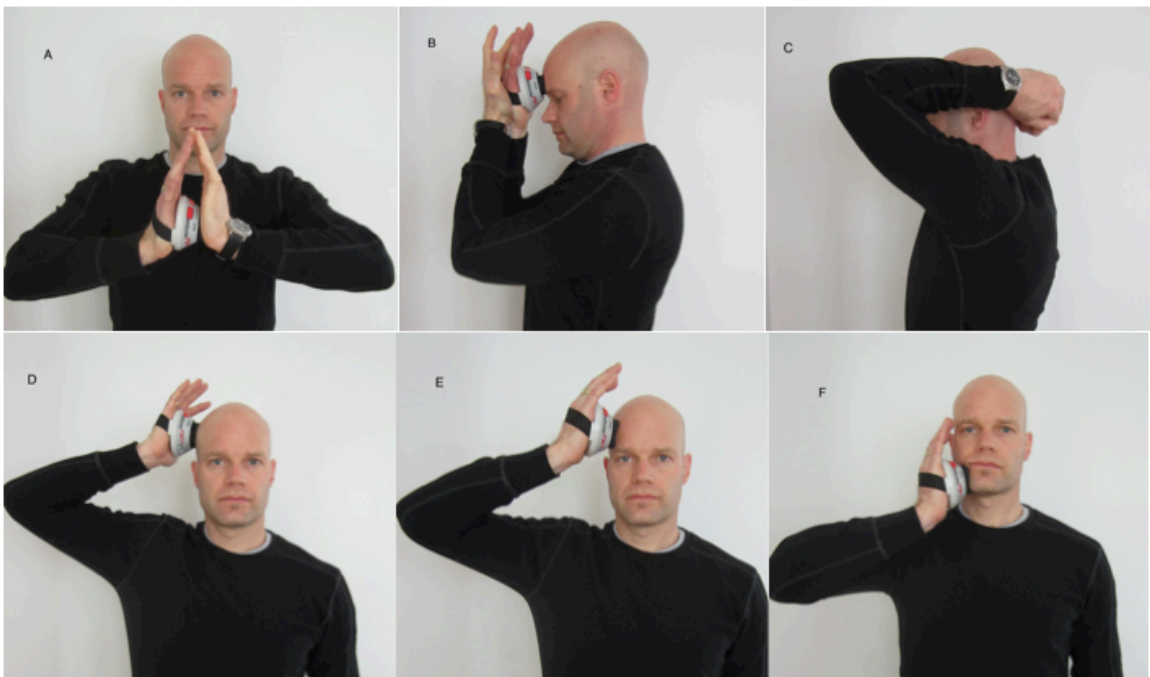


Figure 3.1: Test positions

A. Calibration; B. Forward Flexion; C. Extension; D. Right Side-flexion; E. Right Side-flexion with Rotation; F. Right Rotation.

3.2.3 Data analysis

Subject characteristics were evaluated descriptively (mean, range, SD or frequency as appropriate). Maximum volitional contraction (MVC) values were recorded in a Microsoft® Excel spreadsheet and subsequently loaded into SPSS v21.0 (IBM, USA) for analysis. Recorded EMG data were loaded into LabVIEW 13 (National Instruments®, Texas USA) for filtering and analysis. Each EMG signal was full-wave rectified then filtered using a 4th order Butterworth low pass filter (6 Hz cutoff). The signal was further smoothed using a 20 ms RMS moving window as per Ekstrom and colleagues.²⁷ For each subject, the peak value of the filtered and smoothed signal was recorded for each of the four muscles and for each of the nine test positions. Each processed peak EMG value was then normalized and expressed as a percentage of the reference direction for each muscle.²⁹ For the SCM the reference direction was forward flexion³⁰ and for the UFT the reference direction was ipsilateral side-flexion.²⁷ These normalized values (% of max activation for that particular reference direction) were then analyzed using SPSS. Homogeneity of variance was assessed using Levene's test and normality of distribution assessed using Shapiro-Wilks test for all appropriate analyses listed below.

3.2.4 Specific hypothesis testing

Hypothesis 1 face validity: To show face validity, the E:F was calculated for the two cohorts in the present study and compared to the range of published strength ratios for healthy male cohorts. Only studies that separated healthy males were used for comparison and when possible the age demographic most similar to the current study was selected for comparison. A one-way analysis of variance (ANOVA) was also performed

to analyze the relationships of neck strength values for the eight tested directions. The null hypothesis would indicate that there was no significant difference between strength values for the different tested directions indicating the test lacks face validity. Post-hoc analysis was then performed using the within group factor of direction to confirm that a statistically significant difference existed between flexion and extension strength as well as extension and each unilateral direction test. This was also used to evaluate whether any statistically significant difference existed between the left and right side for each of the unilateral test directions (i.e. side-flexion, side-flexion/rotation and rotation).

Hypothesis 2 known group validity: Mean peak neck strength in each of the eight directions was compared between the FC and CC using multiple single tailed between subjects' t-test with Bonferroni correction ($p < .006$) to test if FC was stronger than the CC. Eight ROC Curves were created, one for each direction, using cohort as the state variable (coded 1 = FC and 0 = CC). Area under the curve (AUC) was calculated for each where an AUC statistically greater than 0.5 was considered significant discriminative ability for that direction.

Hypothesis 3 Convergent validity: Convergent validity was analyzed through one-way ANOVA and post-hoc testing of the relationships described in table 3.1.

3.3 Results

Demographic data for the two cohorts is provided in Table 3.2. The peak strength values for both cohorts and each test position are presented in Table 3.3 along with 95% confidence intervals. For each analysis, homogeneity of variance and normality of distribution can be assumed unless otherwise stated.

Hypothesis 1: The range of E:F for healthy male cohorts from previous studies^{13,14,21,31-43} was found to be 1.08-2.29. The E:F of the present study was 1.23 (95%CI 1.16 to 1.31) for FC and 1.61 (95%CI 1.34 to 1.87) for CC. There was heterogeneity of variances as assessed by Levene's test of homogeneity of variances ($p < .05$). Strength values were statistically significantly different between directions for both cohorts, using Welch's F due to the heterogeneity of variance (FC Welch's $F(7,125.8) = 34.3, p < .01$, CC Welch's $F(7,37.5) = 7.7, p < .01$). Games-Howell post hoc analysis revealed extension strength to be statistically significantly greater than flexion strength (FC 7.3 kgf, 95% CI (2.1 to 12.5), CC 10.1 kgf, 95% CI (0.7 to 19.7)), and all other strength directions (ranging from FC 13.2 to 17.8 kgf, 95% CI (8.3 to 22.6), CC 9.6 to 15.6 kgf, 95% CI (0.1 to 23.6)). There was no statistically significant difference between the right and left side for each unilateral test direction in either cohort ($p > .05$).

Hypothesis 2: The strength of the FC was found to be significantly greater than that of the CC for all test directions (all $p < .01$). The area under the curve calculated for each test direction is presented in Table 3.4 (For each ROC curve see Appendix C). All AUCs were greater than 0.5 (range from LSF = 0.82 to LSF/ROT = 0.99, 95% CI 0.67 to 1.0).

Hypothesis 3: There was a statistically significant difference between surface EMG for each tested direction as determined by one-way ANOVA (Flexion $F(3,148) = 28.0, p < .01$, Extension $F(3,148) = 18.3, p < .01$, RSF $F(3,148) = 23.1, p < .01$ LSF $F(3,148) = 21.0, p < .01$, RROT $F(3,144) = 33.2, p < .01$, LROT $F(3,144) = 38.3, p < .01$). Table 3.4 demonstrates the Tukey Post-hoc tests for multiple comparisons for the relationships described in Table 3.1.

Table 3.2: Demographic details. (SD)

Subject (n)	Age years	Height cm	Weight kg	Neck Girth cm
Football (38)	20.5 (1.4)	188.9 (5.6)	108.1 (19.4)	42.6 (2.6)
Max	23	199	143	50
Min	18	180	178	37.5
Comparator (12)	23.3 (2.3)			
Max	25			
Min	19			

Table 3.3: Mean peak strength values in kgf. (95% CI)

Direction	Comparator cohort (n = 12)	Football cohort* (n = 38)
Flexion	19.1 (15.8 to 22.4)	33.5 (31.7 to 35.5)
Extension	29.3 (25.1 to 33.5)	40.8 (38.2 to 43.5)
RSF	19.7 (16.4 to 23.0)	26.9 (25.4 to 28.3)
LSF	19.7 (17.0 to 22.4)	27.6 (26.0 to 29.2)
RSF/ROT	14.3 (12.2 to 16.4)	23.0 (22.0 to 4.1)
LSF/ROT	13.7 (12.0 to 15.4)	23.2 (22.1 to 24.3)
RROT	15.2 (12.4 to 18.0)	24.3 ¹ (22.5 to 26.1)
LROT	14.6 (12.3 to 16.9)	25.4 ¹ (23.6 to 27.1)

* All differences between groups are statistically significant at to the Bonferroni corrected p-value of $p < .006$.

¹ For football cohort rotation, $n = 37$, kgf = kilogram-force, RSF = right side-flexion, LSF = left side-flexion, RSF/ROT = right side-flexion/ rotation movement, LSF/ROT = left side-flexion/ rotation movement, RROT = right rotation LROT = left rotation. In all differences were statistically significant at the $p < .006$.

Table 3.4: Area under the curve of the Receiver Operating Characteristics (ROC) graph for each isometric test direction.

Test direction	AUC	Asymptotic 95% Confidence interval	
		Lower bound	Upper bound
Flexion	0.98	0.94	1.00
Extension	0.84	0.70	0.98
RSF	0.82	0.67	0.96
LSF	0.89	0.79	0.98
RSF/ROT	0.97	0.93	1.00
LSF/ROT	0.99	0.96	1.00
RROT	0.88	0.78	0.98
LROT	0.94	0.88	1.00

‘Cohort’ as the dependent (state) variable (football cohort versus comparator cohort).

AUC = area under the curve, the closer this value is to 1.00 the better the prediction rate of the test direction. RSF = right side-flexion, LSF = left side-flexion, RSF/ROT = right side-flexion/ rotation, LSF/ROT = left side-flexion/ rotation, RROT = right rotation, LROT = left rotation.

Table 3.5: Percentage of peak muscle activity for sternocleidomastoid (SCM) and upper fibers of trapezius (UFT) muscles in each test position (SD).

Direction (n = 38)	RSCM	LSCM	RUFT	LUFT
Flexion	100	100	45.8 (46.1)	55.3 (48.8)
Extension	21.2 (18.5)	19.3 (21.5)	70.6 (58.3)	62.9 (43.2)
RSF	95.0 (35.6)	33.6 (66.2)	100	48 (40.7)
LSF	41.0 (69.3)	111 (60.1)	44.1 (36.00)	100
RSF/ROT	77.7 (23.7)	69.3 (26.9)	73.4 (53.2)	34.4 (38.6)
LSF/ROT	66.5 (27.1)	77.5 (19.6)	29.5 (26.2)	64.7 (25.5)
RROT (n = 37)	51.7 (22.5)	96.8 (30.7)	54.8 (29.4)	35.7 (25.8)
LROT (n = 37)	98.2 (30.9)	51.9 (18.2)	34.9 (31.7)	60.3 (25.8)

RSF = right side-flexion, LSF = left side-flexion, RSF/ROT = right side-flexion/ rotation, LSF/ROT = left side-flexion/ rotation, RROT = right rotation, LROT = left rotation.

Table 3.6: Tukey post hoc tests for multiple comparisons for anticipated muscle activity pattern by direction.

	Hypothesized relationship of EMG activity (p-value)		
Direction	UFT		SCM
Flexion	RUFT = LUFT (p = .61)	LSCM > LUFT, (p < .01) RSCM > RUFT, (p < .01)	RSCM = LSCM (p = 1.00)
Extension	RUFT = LUFT (p = .88)	LUFT > LSCM, (p < .01) RUFT > RSCM, (p < .01)	RSCM = LSCM (p = 1.00)
RSF	RUFT > LUFT (p < .01)		RSCM > LSCM (p < .01)
LSF	LUFT > RUFT (p < .01)		LSCM > RSCM (p < .01)
RROT	RUFT > LUFT (p < .01)		LSCM > RSCM (p < .01)
LROT	LUFT > RUFT (p < .01)		RSCM > LSCM (p < .01)

UFT = upper fibers of trapezius, SCM = sternocleidomastoid RSF = right side-flexion, LSF = left side-flexion, RSF/ROT = right side-flexion/ rotation, LSF/ROT = left side-flexion/ rotation, RROT = right rotation, LROT = left rotation.

3.4 Discussion

The purpose of this study was to examine the validity of a novel neck strength assessment protocol using self-generated resistance for future clinical use and research. In the absence of a widely-accepted gold standard, our approach was to test a number of smaller hypotheses all of which should lend evidence to support the validity of the protocol. The results generally support our *a priori* hypotheses.

Hypothesis 1 Face validity: The large discrepancy between normative strength values and ratios reported in the literature renders direct comparison difficult. What is consistent among all of these prior studies is that for a healthy population, extension strength is stronger than flexion, unilateral side-flexion and rotation strength, and the strength of the right and left sides are equal. Therefore, for face validity to be supported, any proposed neck strength assessment protocol should also support these relationships. The present study's E:F ratios of 1.23 FC and 1.61 CC are consistent with the range found in prior literature (1.08-2.29).^{13,14,21,31-43} Extension strength was also found to be stronger than each of the unilateral test directions and no statistical difference was found between any of the right and left sided tests. These results appear to support the face validity of the protocol.

Hypothesis 2 Known groups validity: In accordance with expectations, FC demonstrated statistically significantly higher strength values than CC in all tested planes of movement. The AUC under the ROC curve for each of the test directions was significantly greater than 0.5 exhibiting the ability of this protocol to discriminate

between known groups of what are expected to have different levels of neck strength based on training regimen.

Hypothesis 3 Convergent validity: The results of the EMG analysis from the tested method of neck strength assessment are consistent with the proposed hypothesis of neck muscle activation. The SCM muscles' activity reflected its function as a neck flexor when both are working together and as an ipsilateral side flexor and contralateral rotator when they are working unilaterally. The UFT muscles' activity reflected their primary function as an ipsilateral shoulder elevator and head side flexor. It has a secondary function as a neck extensor and rotator that were also demonstrated. These results provide support towards the construct validity of this testing method, insofar as the muscles that should be primarily responsible for generating torque in each direction statistically appear to be those that are most recruited.

3.4.1 Limitations

This study is not without its limitations. Perhaps the most obvious is the narrow subject population of the primary cohort of varsity level football players. Naturally, this is a very small percentage of the population at large, and as seen with Table 3.3, these strength values cannot be generalized to the average population. This fact does harm the study's external validity, however the subject population studied is also a high-risk group for concussion where this type of testing would be most appropriate. Having normative strength values for varsity football players is an important first step towards developing neck strength screening for concussion risk.

One shortcoming of using surface EMG to quantify muscle activity is the lack of precision due to movement of the skin over the underlying muscle, and potential cross-talk from neighbouring muscles. This prevents us from being able to say with absolute certainty that we were gathering EMG from the target muscle. This can be avoided in future analysis by using in-dwelling EMG techniques.

A potential limitation to this method of assessing neck strength is the use of self-generated resistance. This introduces the confounding variable of arm strength into the measurement. Although this did not occur with any of the subjects in the present study, if the individual is not able to generate enough resistance with their arm (whether due to pain, weakness or lack of sufficient range of motion) in the various test positions to overcome their own neck strength this will introduce systematic error into the measurement system, preventing the collection of true neck strength values. This is the reason for the 2-hand calibration test at the beginning of the test procedure, but this does not guarantee that the weakest segment in the chain is in fact the neck muscles.

3.5 Conclusion

This study presents evidence in support of self-generated handheld dynamometry as a valid test of neck strength. Specifically, we found support for the validity of this method for use with varsity level football players and a group of age and sex matched controls. Normative values have been presented to facilitate interpretation of clinical application in the future. Researchers and clinicians may find this assessment approach useful, in that it is practical, affordable and easy to administer. Future studies will build on this initial

research by providing normative strength values for broader populations and evaluating various patient sub-populations (e.g. whiplash, concussion).

3.6 References

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4 Evaluating the effects of a novel neuromuscular neck training device on strength, performance and concussion risk: A pilot study

4.1 Introduction

It is estimated that 70% of university football players experience symptoms consistent with concussion each year.¹ Professional football players with a history of three or more concussions have a five-fold prevalence of mild cognitive impairment after retirement compared to uninjured controls.² Research is therefore underway to explore preventive measures to reduce the risk and impact of concussion.³⁻⁶

Most concussion prevention measures are focused on policy, including changes to rules or equipment with relatively little focus on the individual player. One area of research that has begun to show promise at the player level is the role the neck plays in mitigating the acceleration experienced by the head resulting from player impact.⁷⁻¹⁰ In a review of the biomechanics of concussion, Meaney and Smith¹¹ argue that the primary cause of nearly all concussions are the linear and rotational accelerations of the head resulting from impact. Biomechanical studies have shown that a stiffer and stronger neck decreases head acceleration.^{8,10,12,13} Collins and colleagues⁹ demonstrated that for every one pound increase in neck strength, the odds of concussion decreased by 5% (odds ratio, OR = 0.95, 95% CI 0.92 to 0.98). This line of research presents a potentially promising direction for concussion prevention that focuses on the player rather than equipment or policy changes.

Two studies have examined the effect of neck strengthening on the head kinematic and neck EMG response to sudden head accelerations. Mansell and

colleagues¹⁴ trained 19 varsity level soccer players on an eight-week neck specific resistance training program. The program consisted of neck flexion and extension exercises on an isotonic resistance machine. After completion of the program head kinematic and neck EMG response was re-evaluated and compared to a matched control group. They found no effects of the training on kinematic (head acceleration or displacement), EMG (peak activity, muscle activity area or onset latency for sternocleidomastoid (SCM) or upper fibers of trapezius (UFT)) or head-neck stiffness (defined as the average slope of the line between change in force over the change in displacement).

Lisman and colleagues¹⁵ used a similar training regimen as Mansell and colleagues¹⁴ and found similar results in a group of 16 college-aged males with previous high-school level football experience. After eight weeks of training they found no EMG (absolute root mean square EMG activity for SCM and UFT during the tackling) or head kinematic (peak linear and angular head acceleration, time to peak angular acceleration and head-cervical segment angular displacement) response to a dummy tackling drill. Both of these studies concluded that traditional resistance type training might not be appropriate for improving head kinematic and neuromuscular responses to sudden head accelerations. These authors proposed developing programs that enhance neuromuscular control and dynamic stabilization through higher-speed or plyometric training, i.e. neuromuscular training.

Neuromuscular training has been shown to be effective in preventing injuries in other parts of the body.¹⁶ A systematic review by Emery and colleagues¹⁶ revealed that participation in a neuromuscular training program that included strength, agility, and

proprioception/ balance reduced the risk of lower extremity injuries in youth sport (incidence rate ratio, IRR = 0.64, 95% CI 0.49 to 0.84). An important component of neuromuscular training is proprioception; the awareness of joint movement and position sense.¹⁷ In the cervical spine, there is evidence to suggest traditional ‘isotonic’ strength training programs may actually be detrimental to proprioception. Kramer and colleagues¹⁸ found a 35% *increase* in neck repositioning error following an isotonic only neck strength training protocol without a proprioception component. A resistance program that incorporates proprioception training prevented this deterioration. This evidence of worsening neck proprioception with only traditional strength training may partially explain the lack of improvement in head kinematics after training described by Mansell et al.¹⁴ and Lisman et al.¹⁵

Gilchrist and colleagues¹⁹ performed a critical appraisal of the literature surrounding neck muscle training and its role in concussion risk, which included the studies by Mansell and Lisman above. They also concluded traditional strength training is not likely to be an effective strategy to lower concussion risk and that greater effect may come from training to improve the short-latency rate of isometric force development (e.g. plyometrics). They further suggest that training should be in all planes of movement, including axial rotation.

With this in mind, a method of neuromuscular training has been developed that focuses on multi-planar rotational strength, directed at training dynamic stabilization of the neck through reciprocal plyometric-type neck muscle contractions. This method of training involves a novel neck-training device that uses progressively increasing resistance through self-generated centripetal force (figure 4.1). The purpose of this study

was to collect and analyze pilot data on the feasibility and effect of a seven-week training program with the device on a high-concussion risk population (university football players).²⁰ Feasibility was analyzed through successful subject recruitment, training session adherence, dropout rate and adverse events. Effect size calculations were performed on peak velocity and time to complete 50 revolutions as indicators of performance and training effect. Effects on isometric neck strength before and after training were descriptively compared to a matched control group and used to estimate the magnitude and temporality of performance improvement. *Axial rotation* strength difference between groups was the isometric test of most interest for this study. As a secondary analysis, trained subjects were followed during the subsequent football season to descriptively compare their incidence of concussion with the matched control group and the team average.



Figure 4.1: Neuromuscular training device

4.2 Methods

This was a quasi-experimental non-randomized study design with a matched control group.

4.2.1 Participants and Recruitment

Participants were recruited for this study from the Western University varsity football team. The subjects were selected from a list of players that had enrolled in a previous study - evaluating surface EMG activity of the neck muscles during isometric neck strength testing (unpublished, Chapter 3). The principal investigator met with the head football coach and together they selected 12 players to approach for the intervention cohort and 12 players for the control cohort. The two groups were matched for height (± 5 cm), weight (± 8 kg), age (± 2 years), neck girth (± 3 cm) and playing position. The selection was intended to target players with the highest concussion risk based on playing position and expected exposure (offensive and defensive lines, linebackers and defensive backs).^{21,22} Selection was also based on players that were expected to start or dress during the coming season and, for the intervention group, players who were locally available to train during the seven weeks over the summer of 2014. Subjects were excluded if at the time of training, team medical staff indicated there were any concussion symptoms or musculoskeletal issues that prevented them from participation in their team prescribed pre-season training. Figure 4.2 presents a flow diagram of the subjects through each stage of the study. Formal written informed consent was obtained from all subjects prior to participation in the study. The project was approved by the

Western University Research Ethics Board for Health Sciences involving Human Subjects.

4.2.1.1 *Preparation*

The following were collected from each participant at the start of the study: age, playing position, concussion history, height, weight and years on the team. Neck girth was measured using a flexible measuring tape at the level just below the thyroid cartilage. Isometric neck strength was measured using a handheld dynamometer according to a previously described assessment protocol.²³ This protocol uses self-generated resistance to evaluate strength in flexion, extension and right and left side-flexion, side-flexion/rotation and axial rotation. The average between the right and left sides for side-flexion, side-flexion/rotation and rotation was used for all isometric strength analysis. This isometric strength protocol has shown good test-retest reliability (inter-session ICCs range from 0.87-0.95 for all tested directions) and has evidence of face, convergent and known groups discriminative validity for assessment of neck muscle strength in this population (unpublished, Chapter 3).



Figure 4.2: Flow diagram of participants through stages of study.

4.2.1.2 Training Protocol

Both the intervention and control group continued to participate in their team prescribed off-season training program that also included training on a 4-way uniplanar (flexion/extension and side-flexion) isotonic neck-strengthening machine. The intervention group completed a seven-week neuromuscular training program that included two training sessions per week on the neck-training device.

Pre-test: The intervention group players were fitted with the neuromuscular training device that consisted of a snugly fitted football helmet with flange-mounted bearing attached to the top. From this bearing a 25 cm rod with a 90° bend at the proximal end was attached such that the rod was perpendicular to the bearing and parallel to the floor. At the distal end of the rod is a small 125 g weight. With the helmet tightly secured on the head, participants created coordinated movement of the head using the neck muscles in order to start the weight spinning about its axis while the rest of the trunk remained as motionless as possible. As spin speed increased the small weight provided increased resistance to the neck muscles through centripetal force. Once the subject felt comfortable with the movement they completed three sets of 50 revolutions in each direction of clockwise and counterclockwise. Each of these sets were timed with a stopwatch and recorded (time clockwise (T_{cw50}) and time counter-clockwise (T_{ccw50})). A portable cycling computer was used to count the revolutions and calculate the instantaneous velocity per revolution with the distance of one revolution set to 200 cm. The peak velocity (V_{peak}) in Km/h was then stored on the cycling computer and recorded for each set. The best T_{cw50} , T_{ccw50} and V_{peak} were used as primary outcomes.

The intervention consisted of two training sessions per week, each lasting 8-12 minutes, and separated by 2-3 days. In weeks 1-3 participants performed three timed sets of T_{cw50} and T_{ccw50} . For each session the best V_{peak} was recorded. In weeks 4-7, participants performed five sets of 50 revolutions in each direction, with the best V_{peak} achieved recorded for each session.

Post-test: On the final training session the subjects completed three sets for each T_{cw50} and T_{ccw50} and the V_{peak} and time to complete each set was recorded. After

completing the neuromuscular evaluation, the isometric neck strength protocol was repeated using the handheld protocol. The control group also performed the follow up isometric neck strength testing. The final day of training was within three days of the start of the 2014 fall training camp leading into the 2014 football season.

4.2.1.3 *Concussion incidence:*

A concussion is defined as: “a complex pathophysiological process affecting the brain, induced by biomechanical forces.”^{6(pg1)} Diagnosis of concussion for the purposes of this study was at the discretion of the medical training staff of the football team using a standardized sports concussion protocol. Diagnosis was primarily based on the Sports Concussion Assessment Tool 3 (SCAT-3)²⁴ and the clinical experience of the medical training staff. The medical training staff consisted of a certified athletic therapist, a sport medicine physician and an orthopaedic surgeon. Any player that was taken out of a game or practice or missed at least one practice or game on the advice of the medical training staff for potential concussion symptoms was deemed a positive diagnosis of concussion for analysis purposes.

4.2.1.4 *Adherence:*

Adherence was measured as the number of sessions each subject attended over the maximum number of sessions (n=14). Drop out rate was defined as subjects who completed baseline (pre) testing for the intervention group with the neuromuscular training device but did not complete the final follow up (post) testing. Questions about adverse events from the previous session were asked at each subsequent session.²⁵ Of particular interest were any acute head or neck pain associated with the use of the

neuromuscular training device. As this method of training involves a novel method of exercising the neck muscles it was expected that subjects might experience delayed onset muscle soreness.²⁶ If the pain or duration were greater than the subjects had experienced with other neck training programs, they were to inform the primary investigator. Other adverse events regardless of whether they were clearly due to the training regimen (e.g. headache, dizziness) were collected for purposes of informing future pragmatic research.

4.3 Data Analysis

Subject characteristics were explored descriptively (mean, 95% CI), along with concussion incidence. In the intervention cohort, recruitment rate (defined as percent of approached subjects who were both eligible and consented to take part in the study), adherence rates, dropouts and adverse events were also recorded. For the purposes of informing future research, effect sizes (Cohen's *d*) were calculated for the differences in performance parameters pre and post training on the neuromuscular device and for the differences in changes in isometric strength values between the intervention and control cohort. Effect sizes were calculated using G*Power (ver 3),²⁷ while all other analyses were conducted in SPSS (v21.0, IBM, USA) unless stated otherwise.

4.4 Results

The characteristics of the two cohorts are presented in Table 4.1. In total, a 67% recruitment rate was achieved in the intervention cohort. This was comprised of a consent rate of 75% (9 out of 12 agreed to participate) and an eligibility rate of 89% (8 out of 9). The single ineligible player was removed due to sustaining an unrelated injury prior to pre-season training preventing him from participating in team training. Of those

successfully recruited for the intervention arm, there were no dropouts or adverse events reported for the duration of the study (dropout rate = 0%, adverse events reported = 0). Subjects in the intervention group attended an average of 85% of the 14 training sessions (mean = 11.9, range = 11 to 14). Pre and post neuromuscular performance parameters over the seven weeks of training along with effect sizes and achieved power are presented in Table 4.2. The change in V_{peak} over each training session during the seven weeks of training is displayed in Figure 4.3.

Table 4.1: Subject demographics. (95% CI)

	Intervention (n=8)	Control (n=10)
Neck Girth (cm)	43.8 (42.2 to 45.4)	43.5 (41.6 to 45.4)
Age (years)	20.8 (19.8 to 21.7)	20.8 (19.7 to 21.9)
Height (cm)	188.6 (184.3 to 192.9)	190.3 (186.9 to 193.7)
Weight (KG)	112.4 (97.5 to 127.3)	113.9 (101.4 to 126.4)

The average strength values for the intervention and control groups pre and post testing are presented in Table 4.3 along with the mean change values and calculated effect sizes of the difference between control and intervention. Axial rotation, the isometric strength test of most interest, demonstrated the largest effect size with the highest achieved power and the largest mean change difference between the control and intervention cohorts (Cohen's $d = 1.30$, 95% CI 0.22 to 2.25, achieved power = 0.84,

mean difference = 4.7 kgf). Figures 4.4-4.8 present pre and post isometric strength values for the intervention and control groups for each of flexion and extension and the left and right side average for the unilateral test directions.

There were no concussions reported for individuals in the intervention group (0%) compared to two in the matched control cohort (20%). Including these two concussions there were a total of eight reported for the rest of the dress roster players (N=52, 15.4%) over the course of the 2014 football season.

Table 4.2: Pre and post training performance (n = 8). (95% CI)

	Pre-test	Post-test	Effect size (Cohen's <i>d</i>)	Achieved power*
V_{peak}	14.8 (11.0 to 18.6)	30.4 (29.1 to 31.7)	4.64 (2.58 to 6.19)	1.00
T_{cw50}	32.3 (21.2 to 41.3)	16.6 (14.0 to 19.1)	1.64 (0.43 to 2.67)	0.99
T_{ccw50}	33.0 (21.4 to 44.7)	14.4 (13.6 to 15.2)	1.79 (0.63 to 2.95)	0.99

V_{peak} = speed presented in Km/h, and the circumference of one revolution is set to 200cm, **T_{cw50}**, **T_{ccw50}** = Time to complete 50 revolutions clockwise and counter clockwise direction respectively in seconds

*Achieved power for one-tailed matched pairs t-tests, alpha = .05

Table 4.3: Isometric strength values pre and post testing (kgf) with mean change and effect sizes. (95% CI)

		Pre-test	Post-test	Change	Effect size (Cohen's <i>d</i>)	Achieved power*
Flexion	Con	33.5 (28.1 to 38.9)	39.7 (34.9 to 44.6)	6.3 (2.0 to 10.5)		
	Int	37.0 (32.4 to 41.6)	40.6 (34.4 to 46.9)	3.6 (0.6 to 6.6)	-0.53 (-1.44 to 0.44)	--
Extension	Con	45.3 (38.0 to 52.6)	44.2 (36.2 to 52.2)	-1.1 (-5.1 to 2.9)		
	Int	43.8 (38.7 to 48.8)	45.7 (39.0 to 52.4)	1.9 (-2.1 to 6.0)	0.69 (-0.30 to 1.61)	0.40
Side-flexion	Con	27.2 (24.6 to 29.9)	28.1 (25.0 to 31.3)	0.9 (-1.8 to 3.7)		
	Int	28.6 (25.0 to 32.3)	31.2 (27.8 to 34.6)	2.6 (1.6 to 3.5)	0.53 (-0.44 to 1.45)	0.28
Side-flexion/ Rotation	Con	22.3 (19.8 to 24.8)	23.7 (20.0 to 27.3)	1.3 (-0.6 to 3.3)		
	Int	24.9 (23.1 to 26.6)	26.2 (23.8 to 28.7)	1.4 (-0.4 to 3.2)	0.02 (-0.91 to 0.95)	0.05
Axial Rotation	Con	25.2 (20.0 to 30.4)	24.1 (19.0 to 29.2)	-0.3 (-2.7 to 2.1)		
	Int	25.9 (21.7 to 30.2)	30.3 (27.3 to 33.3)	4.4 (0.95 to 7.8)	1.30 (0.22 to 2.25)	0.84

kgf = kilogram-force, Int = intervention (n = 8), Con = control (n = 10), effect size calculated using the difference between the mean change in strength values of intervention and control. *Achieved power for one-tailed independent t-tests, alpha error = .05

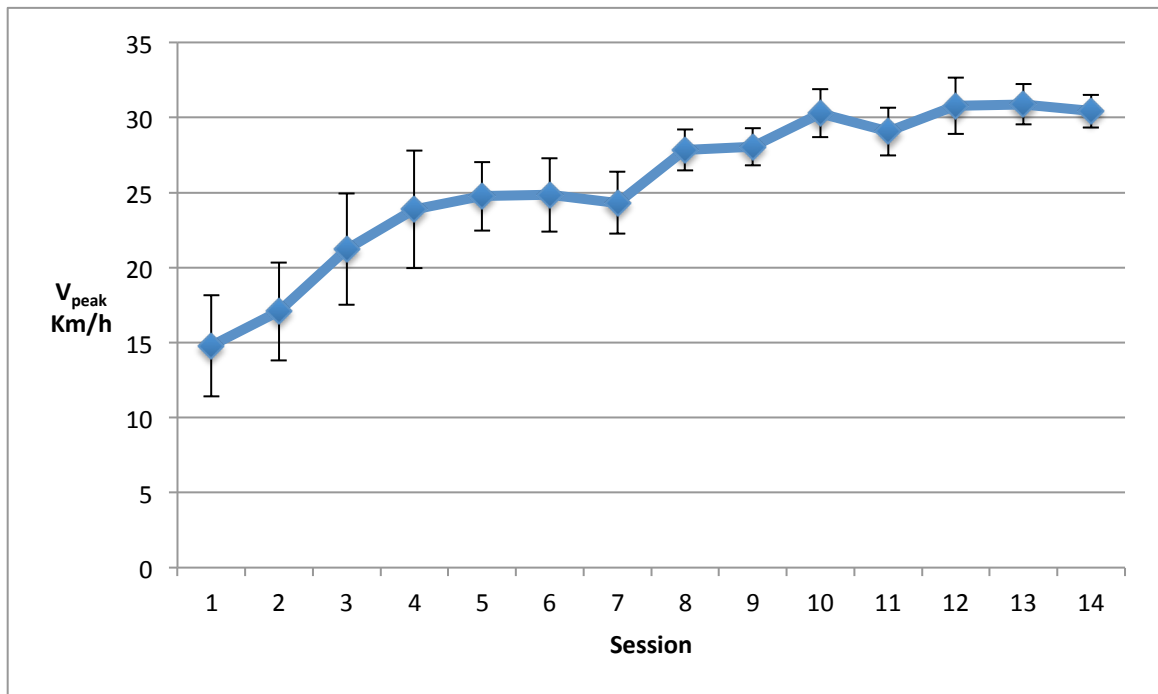


Figure 4.3: Mean peak velocities for each of the 14 training sessions with 95% confidence intervals.

Figures 4.4-4.8: Isometric strength values for control and intervention group at time pre and post by direction. Error bars are 95% CI.

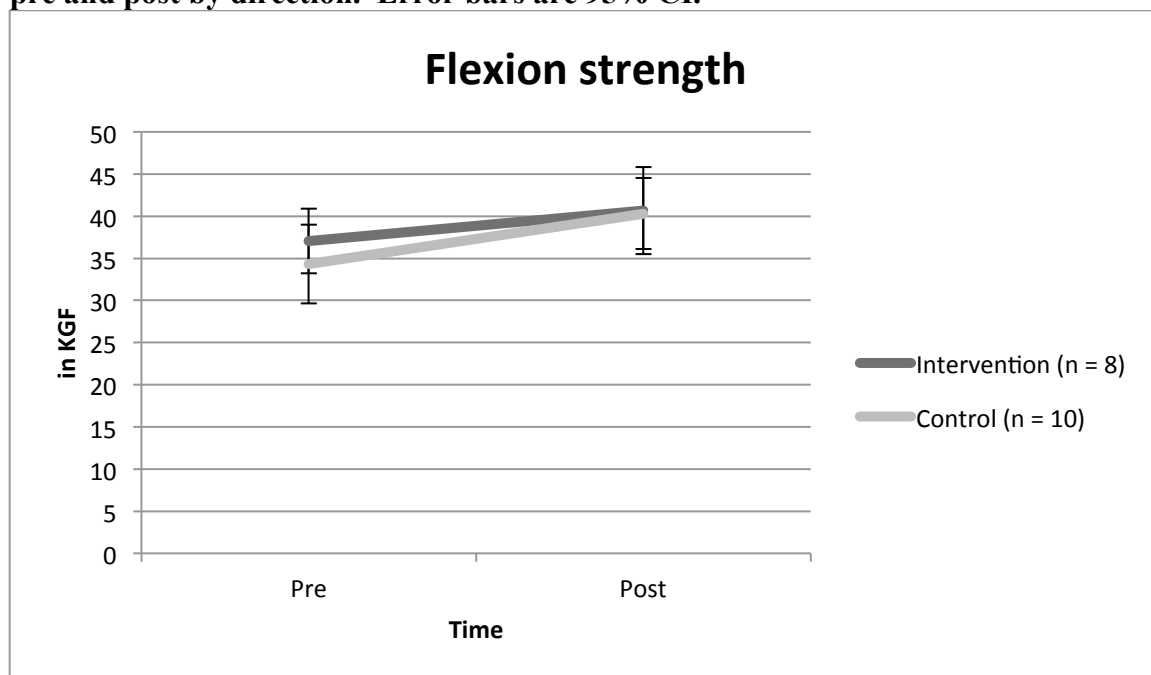


Figure 4.4: Pre and post isometric flexion strength values graph

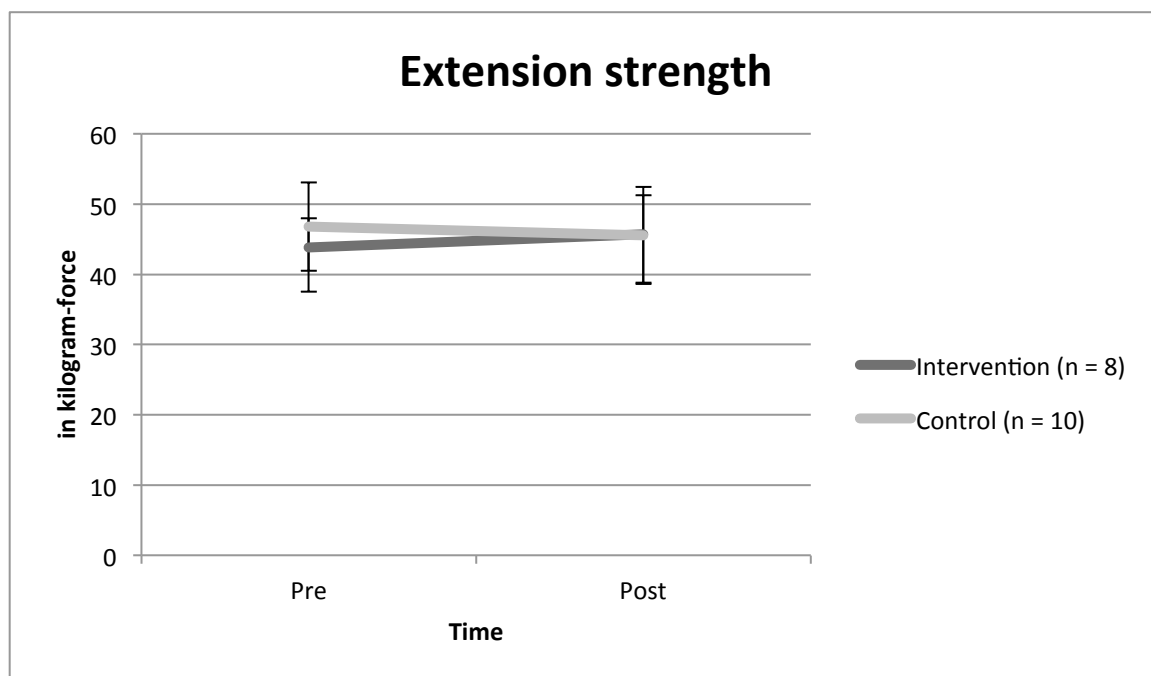


Figure 4.5: Pre and post isometric extension strength values graph

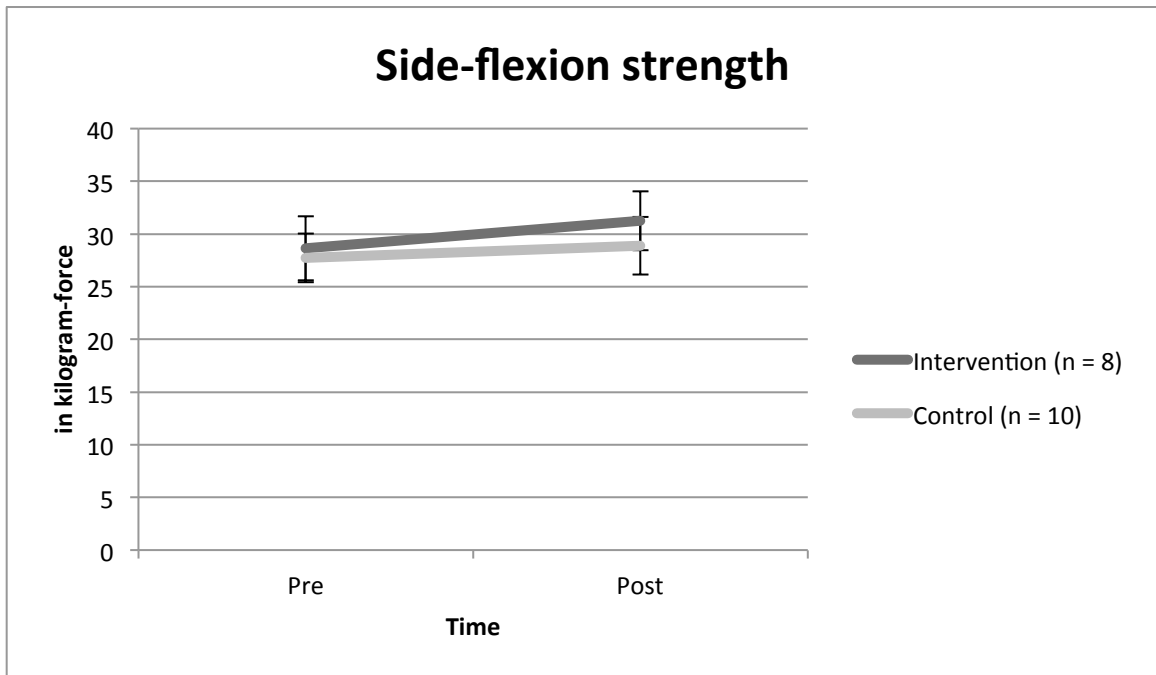


Figure 4.6: Pre and post isometric side-flexion strength values graph (average between right and left sides)

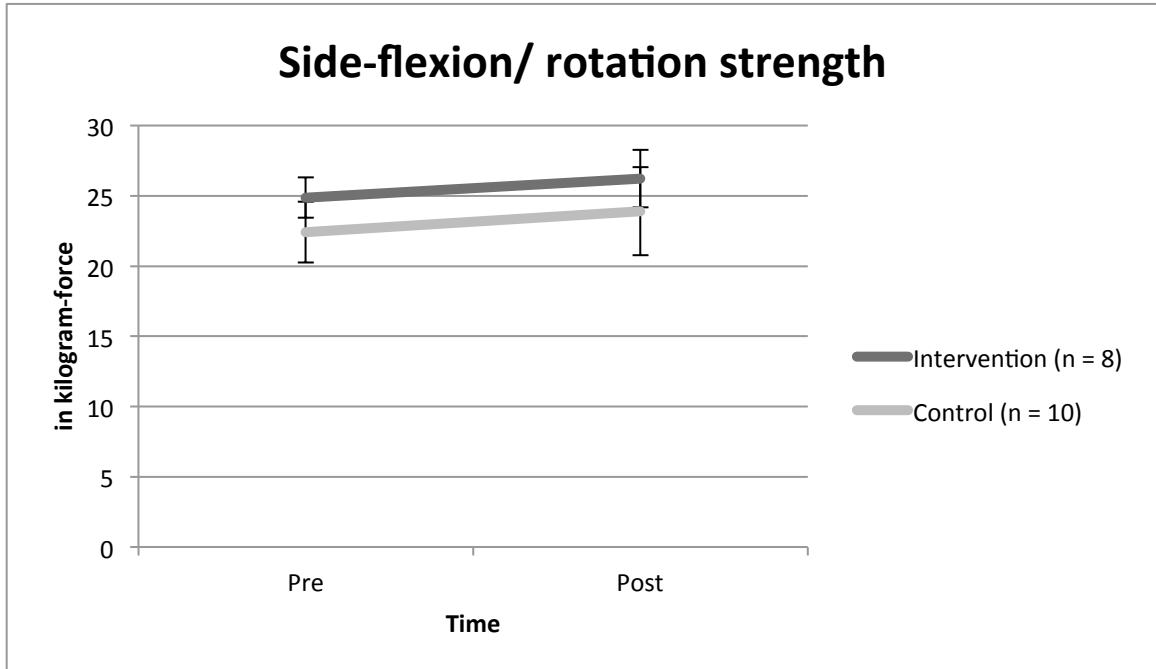


Figure 4.7: Pre and post isometric side-flexion/ rotation strength values graph (average between right and left sides)

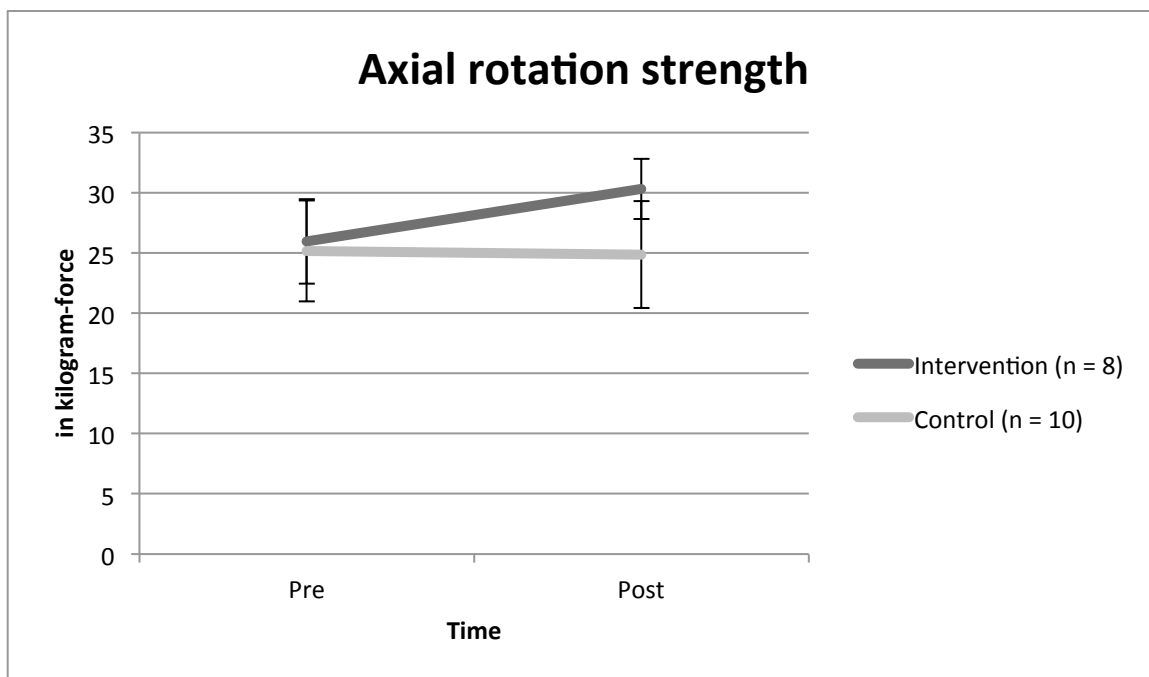


Figure 4.8: Pre and post isometric rotation strength values graph (average between right and left sides)

4.5 Discussion

The purpose of this pilot study was to assess the feasibility and estimate the effect of training with a novel neuromuscular training device in a cohort of high-concussion risk football players. Two-thirds of the subjects approached for involvement in the study were successfully recruited and completed the training program. Subjects who trained on the device demonstrated an 85% adherence rate with no dropouts or adverse events.

Predictably, the results indicate that training on the neuromuscular device improves performance on the device. V_{peak} more than doubled and both T_{cw50} and T_{ccw50} times were halved after the training. This method of training may also be an effective means of improving neck axial rotation strength as shown by a large effect size of 1.30 and 95% confidence intervals that exclude zero (0.22 to 2.25). The average improvement

of 4.4 kgf in the intervention group compared to the small decrease of 0.3 kgf in the control group was the largest mean change difference found in this study. Because both the intervention group and control group continued their standard pre-season training that involved using the 4-way neck machine it is not surprising that there was evidence of improvement over time for flexion, side-flexion and side-flexion/rotation for both groups. The 4-way neck machine trains the neck isotonicly in these directions and is known to improve isometric neck strength.²⁸ However, axial rotation strength is not trained with the 4-way neck machine. Viano and colleagues¹² showed that in professional football most concussions occur from contact to the front of the helmet causing primarily axial rotation. If this is true, and if the results from Collins and colleagues⁹ study are generalizable to include axial rotation strength, then training on this device may decrease the odds of concussion by 5% or more (4.7 kgf = 10.3 pounds increase neck strength per side, equating to over three pounds of net increase in a composite neck strength score that includes axial rotation).

Secondary analysis was to explore incidence of concussion risk in the intervention group compared to the matched controls and the rest of the dress roster players. It is encouraging that none of the intervention group experienced a concussion over the course of the following season compared to two in the matched control group and eight overall for the rest of the dress roster players.

This pilot study is the first to examine a neuromuscular training device that was developed using a theoretical rationale that is consistent with the state of the literature on how to decrease an individual's concussion risk through neck training.^{7,9,10,12,14,15,19} The preliminary results of the neuromuscular training program presented in this pilot study

are at least not in conflict with the training proposed in the literature to decrease concussion risk.

4.5.1 Limitations

There were several limitations to this study. First, because this was a pilot study, statistical significance was not calculated for any comparisons. Although the effect size and achieved power for improvements in axial rotation strength would suggest significance ($d = 1.30$, power .84), this pilot study was not intended to make statistical inferences nor was it adequately powered for multiple comparisons. While it is believed the type of training used for this study enhances the neuromuscular control and dynamic stability of the neck,^{7,14,15,19} testing only isometric strength does not provide a means of measuring this. The control group did not test on the training device, so it cannot be stated with absolute certainty that the improvement in performance on the device was not simply due to time or some other confounding variable. The subjects were not randomly selected for involvement in the study, therefore some form of selection bias by the principal investigator or head coach may have inadvertently affected the selection. The subjects and investigators were not blinded to the type of training the subjects received allowing for the potential of measurement bias during the post training testing. The control and intervention groups use of the 4-way neck machine, and other training techniques was not documented or controlled. Other confounding factors, such as concussion history, were not analyzed in this pilot study but could be an important covariate to analyze in future studies. Finally, although the medical staff was intentionally not informed of which players were in the intervention group, they were not

formally blinded to this, allowing for the potential of measurement bias in concussion incidence.

4.6 Conclusion

The results of this pilot study demonstrated that the type of neuromuscular training presented here is feasible for high-risk football players. The results also provide guidance for design and conduct of a fully powered study to determine the training effect of the device on multi-planar neck strength and incidence of concussion. For instance, this pilot determined that a trial comparing improvements in side-flexion strength using the device over and above a control group using a 4-way neck machine could be conducted by approaching a total of 135 football players. With an expected 67% successful recruitment rate, the analysis of 45 subjects per arm would achieve 80% power to detect differences of 1.7 kgf or more in side-flexion strength. This sample size would also be sufficient to compare differences in rotation strength while compensating for multiple comparisons. The results of this trial could then be used to estimate the effect of multi-planar neck strength and device performance on the incidence of concussion.

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5 Discussion

5.1 Summary

The purpose of this thesis was two-fold. Our first purpose was to develop a method of evaluating neck strength for adoption into clinical, field and research settings. Our second purpose was to explore the training effect of a novel neuromuscular training device. For adoption into clinical field and research settings, the method of evaluating neck strength needed to satisfy four criteria. First and foremost, it needed to be safe to administer (for both assessor and individual being assessed). Second, the method needed to be capable of assessing neck strength along all three planes of motion of the neck – specifically flexion/extension, side-flexion and axial rotation. Thirdly, for adoption into a field or sport setting, it needed to be portable, practical and easy to administer regardless of the skill level of the assessor. For this to be the case, it needed to be independent of external equipment for stabilization (e.g. belts, plinths, walls, second assessor, etc...). Fourth, it should have at least preliminary evidence of validity and reliability regardless of the strength of the investigator or the strength of the individual being tested. This is of greatest concern when the individual being assessed is much stronger than the assessor, which would commonly be the case when assessing high-level contact sport athletes. Given these criteria, the method presented using self-generated resistance was deemed the best option. This method, although perhaps imperfect, satisfies these four criteria.

The second purpose of this thesis was to explore the training effect of a novel neuromuscular training device. The goal of the creation of this device was to strengthen the neck in a manner that would help mitigate acceleration forces applied to the head, and ultimately decrease the risk of concussion. Although this is an ambitious goal, the results

of this thesis are generally consistent with the theoretical underpinnings of the device and the anticipated results. At the very least, this thesis provides preliminary evidence that the device is safe and that it does not overtly dispute the underlying theory it was built upon.

Chapter two was a reliability study of the neck strength assessment protocol using self-generated resistance. This study outlined the protocol and tested the intra- and inter-session reliability of the protocol in a healthy younger adult population. The intersession ICCs found for each tested direction indicated overall excellent reliability in this population and provided estimates of the change in score required to confidently surpass measurement error.

Chapter three examined the validity of the neck strength assessment protocol by testing three *a priori* hypotheses. This approach was chosen as there currently exists no gold standard by which to compare this method in order to determine the concurrent criterion-related validity.¹⁻⁴ The three hypotheses tested were face validity, known groups discriminative validity and convergent validity. Face validity showed strength relationships within subjects for the various test directions were consistent with those found in the literature (See Chapter 1). Known groups discriminative validity showed the ability of the method to correctly discriminate between two known groups of individuals with expected neck strength differences. Finally, convergent validity was demonstrated through EMG analysis. Expected relationships of muscle activity between the right and left side sternocleidomastoids (SCM) and upper fibers of trapezius (UFT), in light of what is currently known about the primary functions of those muscles, were confirmed through statistical analysis. Although validity is a continual process this study provides

the initial progress towards establishing the protocol as an adequately valid method for assessing isometric neck strength.

Chapter four was a pilot study to assess and analyze data on the feasibility, safety and effect of training with a novel neuromuscular training device to inform future research. This study was the first of which I am aware to examine a method of training designed to train the neck in a manner consistent with the state of the literature on decreasing concussion risk (see Chapter 1).⁵⁻¹³ The presented training method utilizes self-generated centripetal force to produce dynamic resistance that is dependent on the neuromuscular strength and coordination of the individual. As the speed of the revolving weight increases, the tension the neck must generate to keep the weight spinning increases, as does the speed of contraction of alternating reciprocal neck muscles. The study demonstrates feasibility in a football player cohort with a 67% success rate for recruitment into the training cohort of the study. This training cohort recorded no adverse events for the duration of the study and recorded an adherence rate of 85% to the training protocol. The study provides initial evidence of a training effect from use of the device over a seven-week period in varsity football players. It showed an improvement on performance on the device along with potential improvements in neck rotation strength compared to a control group. Effect sizes were presented to allow future studies to determine the sample sizes required for fully powered studies. Although this was only a pilot study and no statistical inferences were made, it is encouraging that none of the intervention group ($n = 8$) experienced a concussion during the following football season compared to two in the control group ($n = 10$). This study provides guidance for future

studies in evaluating the effect of this neuromuscular training device in high-concussion risk athletes.

5.2 Limitations

This thesis is not without its limitations. Although the neck strength evaluation protocol satisfied the initial criteria for adoption into field and clinical setting it does so by evaluating strength using a make test. It was reasoned that using a make test for evaluating high-level contact sport athletes would be preferable because this would require less force than using a break test consequently being safer and easier to administer. However, when examining neck strength as a proxy for concussion risk arguably a break test would be more theoretically inline with concussion risk. This is because a break test examines the eccentric contraction strength of the muscles which is the type of contraction the neck muscles would be required to perform in order to decelerate the head after impact. Furthermore, a break test strength value also incorporates the passive resistance forces generated by the non-contractile tissues. These passive resistance forces also contribute to the overall neck stiffness and it is this property of the neck that is suspected of contributing the most to protecting the head from concussive forces.⁸⁻¹⁰ A make test was chosen for these studies because it was still aligned with our underlying theory and believed to pose a lower risk of adverse events.

The pilot study in Chapter 4 also contained several limitations. As noted, the selection of the intervention and control group was not randomized but was based on local availability, player position and highest expected concussion risk exposure. Due to this lack of randomization a potential selection bias exists. Furthermore, because the primary investigator was not blinded to which group each player was from, the potential for measurement bias at the follow-up neck strength assessment also exists. Finally, confounding variables such as previous concussion history was not examined which may partially explain the difference in concussion incidence between the two groups.

5.3 Future research

Although the primary goal of training on the neuromuscular training device is to lower concussion risk in individual's who use it, it would also be expected to demonstrate training effects in secondary head/neck kinematics and muscle response characteristics. Specifically, increased head/ neck stiffness leading to decreased peak head acceleration and head displacement to a sudden external force applied to the head; improved neuromuscular response represented by a decrease in the muscle onset latency of key muscles in response to a sudden perturbation. An experimental setup to test this should use perturbations in all three planes of movement of the head and neck, i.e. flexion/extension, right and left side-flexion, right and left axial rotation. Such a setup should also have the capability of delivering the external force in a manner such that the individual being tested does not know from what direction it is coming. This is to more closely mimic unanticipated or "blind side" hits, which appear to be more likely to cause concussion.¹¹ For helmeted contact sport athletes, the setup should allow these individuals to wear their own helmet and have the force applied to the helmet to most closely mimic the field of play. It should also measure the kinematics of the helmet and the head separately. This will help assess the relationship between helmet kinematics and head kinematics. As many helmet manufacturers introduce accelerometer systems into their helmets, knowing the relationship between head and helmet kinematics may help further refine injury threshold algorithms. Assessing head and helmet kinematics separately also provides the potential for sub-group analyses that may help determine the best fit of a helmet to help decrease resultant head acceleration.

Proper EMG assessment is required to assess muscle onset latency. Superficial muscles of interest could include sternocleidomastoid, upper fibers of trapezius and splenius capitus. EMG analysis should sample at a minimum frequency of 1000HZ to allow proper filtering and post-processing to analyze muscle onset latency and magnitude of response. For muscle onset latency evaluation, the EMG system must be time synchronized across all muscles and to the time of the external force application. To prevent contamination of the muscle onset latency from the startle response or accommodation, the individual must not be able to hear or anticipate when the external force will be applied. This can be achieved through wearing noise cancelling headphones with a distraction auditory stimulus along with blinders to prevent picking up on visual cues, e.g. seeing the examiner press the release trigger.

An experimental setup that accomplished these parameters was attempted through a piloted protocol that showed promise but still requires further refinement before it can be fully utilized in research. This will be a primary goal of future research in this field.

Future studies should also explore the relationship between isometric neck strength, performance on the neuromuscular training device and incidence rate of concussion. As an example, this could be done by assessing the neck strength and performance on the device of all players on a football team prior to the start of a season, then following them for the season and recording concussion incidence for that season and calculating the relative risk depending on selected cutoff values for neck strength and performance on the device.

Another study of interest would be to examine the relationship between neck strength in each individual plane of motion and the cumulative acceleration loads experienced in each of these planes of motion during the course of a season. This can be done using tri-axial accelerometers implanted in the player's helmets, then assessing each individual plane of linear acceleration and each axis of rotational acceleration and correlating this to the respective neck strength value.

5.4 What this study adds

This thesis provides a novel method for evaluating neck strength along all three planes of motion of the neck that is highly reliable and has preliminary evidence of adequate validity. This method is safe, portable, easy to administer and not dependent on the strength of the assessor or external stabilization making it ideal for clinical, research, and field use. The ability to assess axial rotation strength, along with the other directions, may provide further insight into the relationship of neck strength and concussion risk since acceleration in this plane of motion may be associated with a higher risk of concussion injury.^{7,9}

This thesis also provides, to the best of our knowledge, the first attempt at neuromuscular training for the neck that is based on a theoretical rationale that is consistent with the state of the literature on how to decrease an individual's concussion risk. The results provide guidance for future fully powered studies. Although only a pilot study was conducted, the results would indicate that the presented method of

neuromuscular training is safe and may be an effective approach to improving axial rotation strength.

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6 Appendices

APPENDIX A: Screening Protocol and Assessment Protocol

Screening Protocol

To ensure participant safety, the following tests were performed prior to completing the neck and upper quadrant assessment protocol:

1. Participant must demonstrate full active range of motion with overpressure in six planes of movement including flexion, extension, side-flexion, side-flexion rotation, and pure rotation.
2. Participant must not experience pain or other symptoms during the 4 quadrant combined planes test, which includes flexion/side-flexion, side-flexion/flexion, extension/side-flexion, side-flexion/extension.
3. Participant must not experience pain or other symptoms during the Spurling's compression test.

Assessment Protocol

Initial Starting Position: Participant is sitting on a stool with both feet flat on the ground, neutral spinal alignment, and a mirror directly in front.

Tester position: The tester is standing behind the participant for all positions in order to give feedback regarding limb and dynamometer positioning

Instruction: In each test position, you are going to build up to maximum resistance over three seconds. You may stop at any point should you feel any pain greater than the response to maximal muscle contraction or if you have any dizziness during the test.

Demonstration: The tester demonstrates each test position before the participant performs the movement.

Testing Positions

A. Calibration



2-hand compression 2-hand compression

Position of Limb segment: Palms flat and facing each other, hands in front of chest, elbows bent and parallel to the floor.

Dynamometer Placement: Between palms of both hands.

Instructions: Hold the MicroFET between the palms of both hands without interlocking your fingers. Push your palms together as hard as you can, keeping your elbows parallel to the floor.

B. Forward Flexion



Position of Limb segment: Shoulders in 90 degrees of forward flexion, elbows flexed to over 90 degrees, one hand overlapping the other, head in a neutral position.

Dynamometer Placement: Centre of the forehead, resistance applied with both hands.

Instructions: Keep your elbows tucked in and push your head into your hands as hard as you can.

C. Extension



Position of Limb segment: Arms in full flexion, elbows flexed and tucked in close to the head, hands overlapped behind head, head in a neutral position.

Dynamometer Placement: Base of the occiput, resistance applied with both hands.

Instructions: Push your head back into your hands as hard as you can.

D. Pure Side-Flexion



Position of Limb segment: Ipsilateral arm placed in external rotation and abduction.

Elbow is in line with the shoulder and flexed.

Dynamometer Placement: Above and in-line with the ear. Resistance applied with ipsilateral hand.

Instructions: Think about bringing your ear to your shoulder, pushing your head into your hand as hard as you can.

E. Side-Flexion/Rotation



Position of Limb segment: Shoulder in 90 degrees of abduction, slight external rotation, 60 degrees in the horizontal plane from neutral.

Dynamometer Placement: Temple, above the lateral aspect of the eyebrow. Resistance applied with ipsilateral hand.

Instructions: Think about looking down and to the side toward your underarm, pushing your head into your hand as hard as you can.

F. Pure Rotation



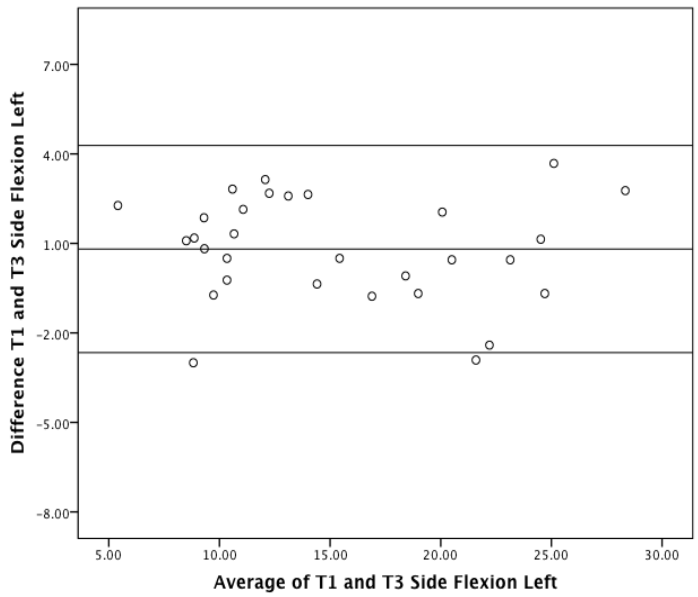
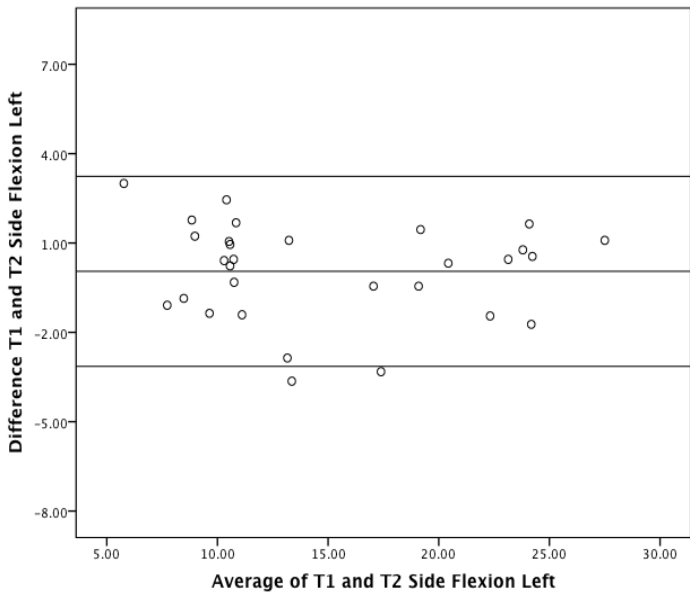
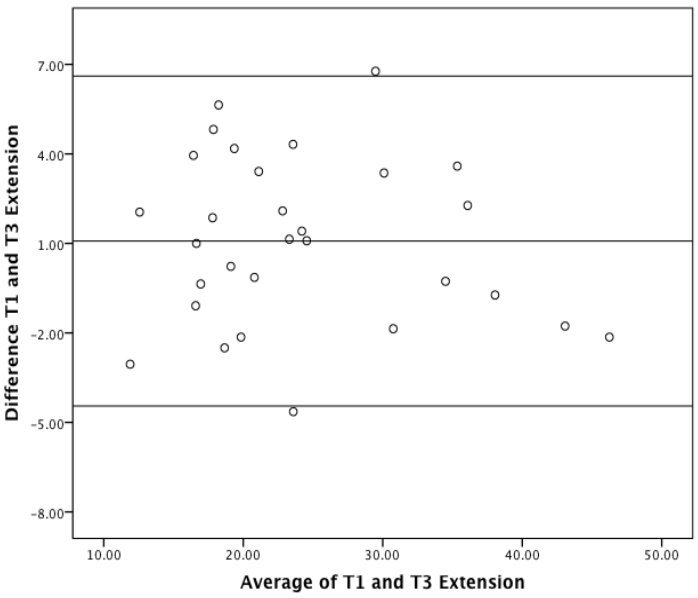
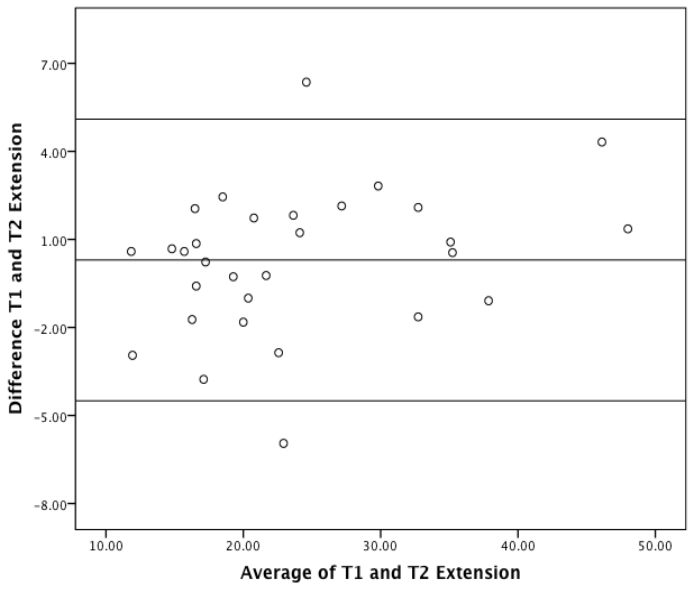
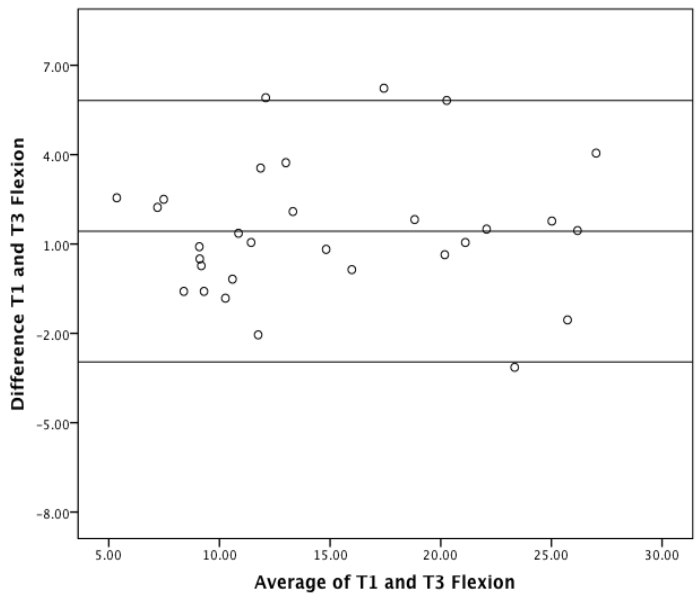
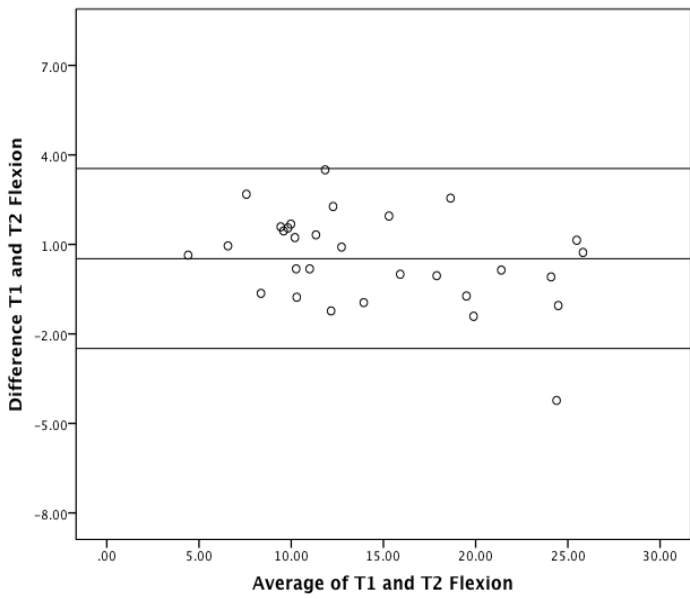
Position of Limb segment: Shoulder in 90 degrees of abduction, elbow fully flexed, fingers pointing upward

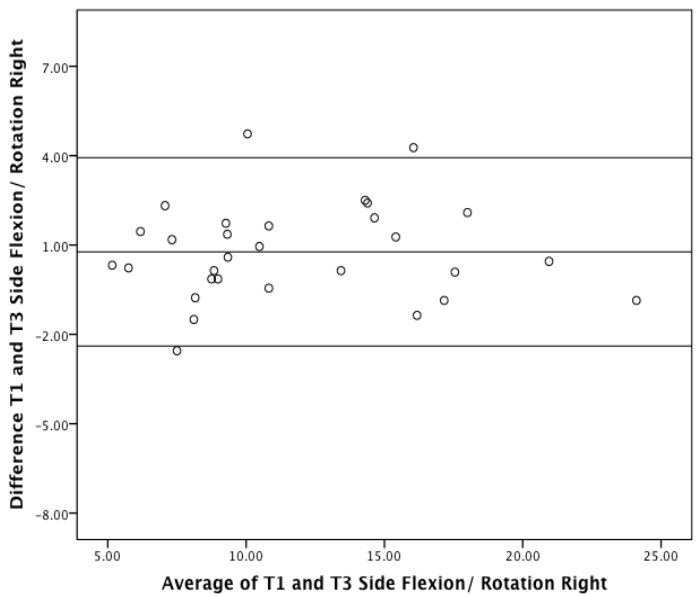
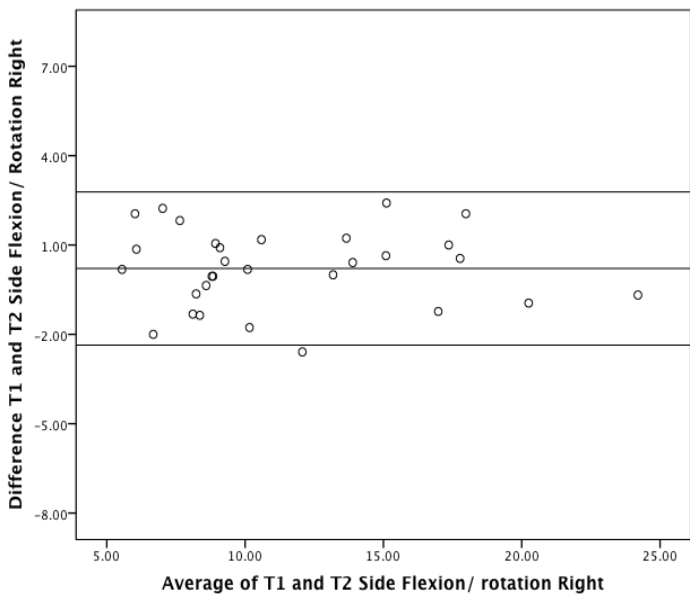
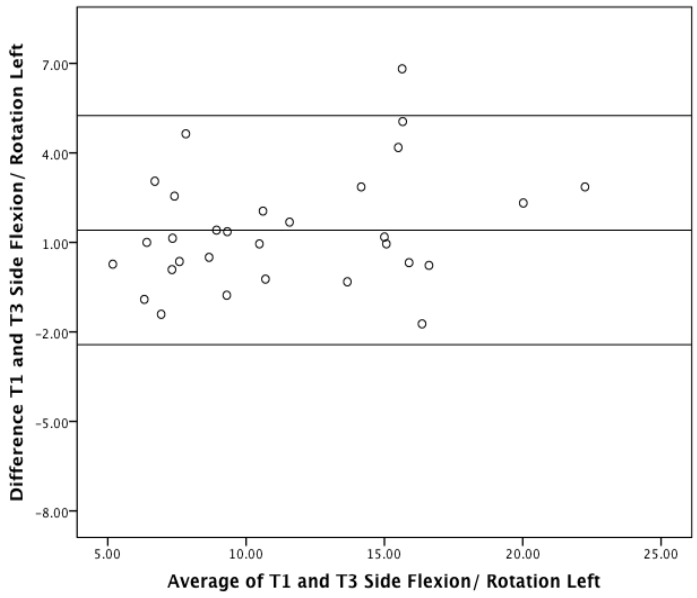
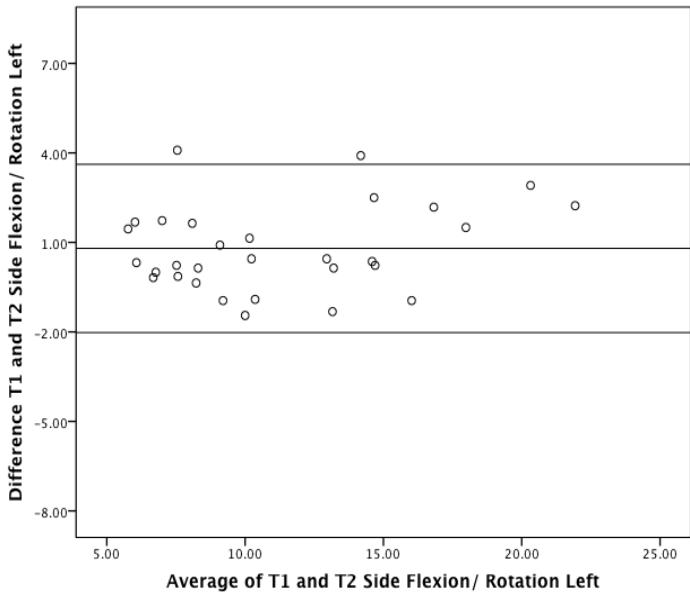
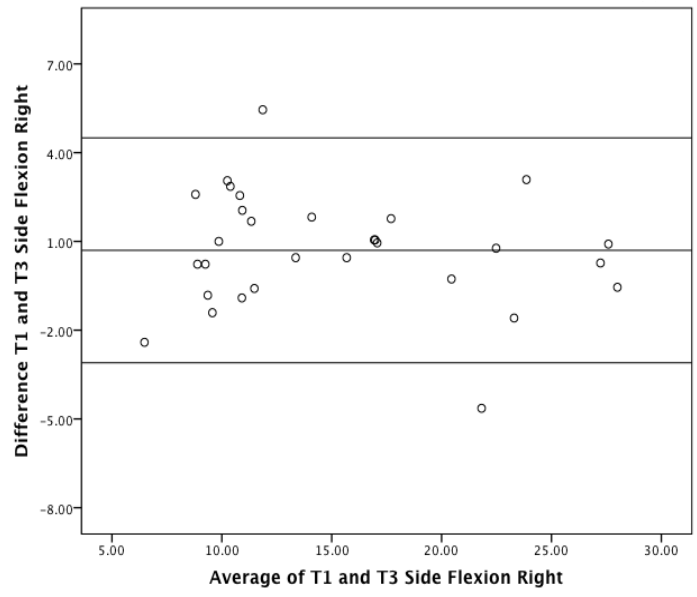
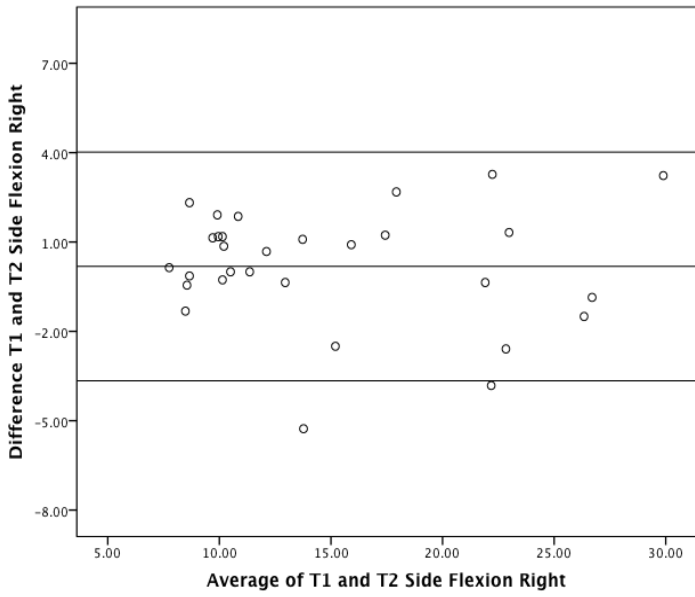
Dynamometer Placement: Along the jaw close to the chin. Jaw is clenched during testing and force applied with ipsilateral hand.

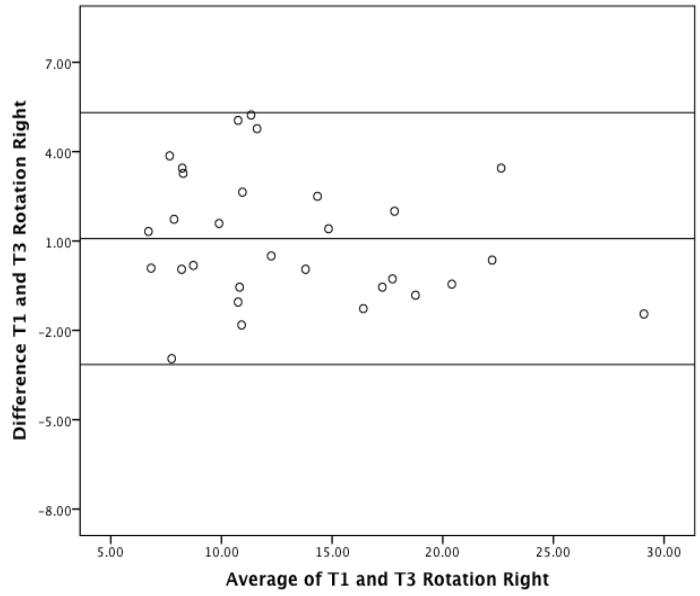
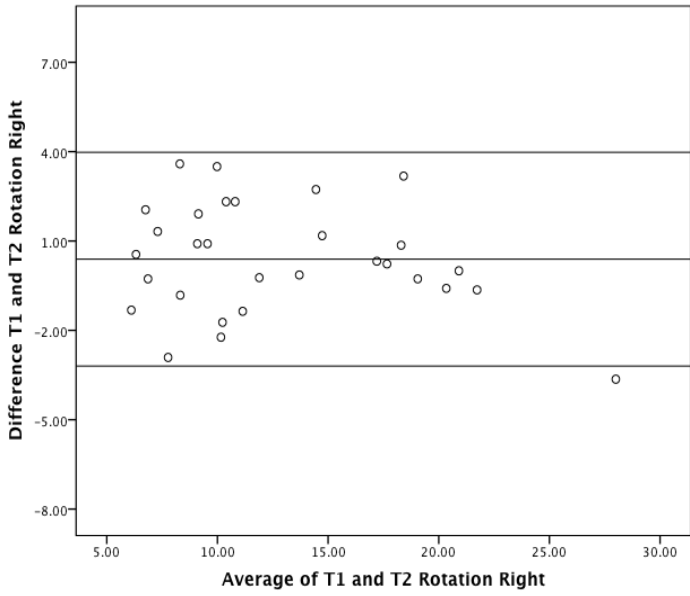
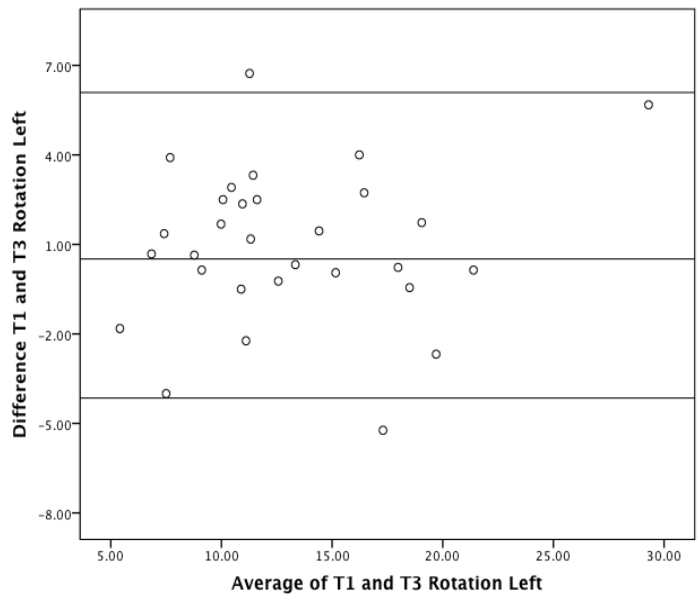
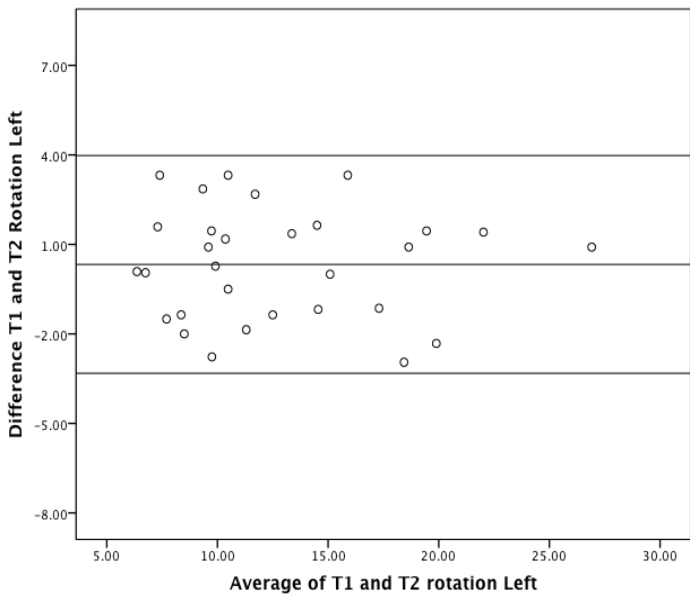
Instructions: Think about turning your head to look over your shoulder, pushing your head into your hand as hard as you can.

APPENDIX B: Bland–Altman plots showing 95% levels of agreement for the various test positions from Chapter 2

T1 = initial assessment, T2 = intra-session, T3 = inter-session

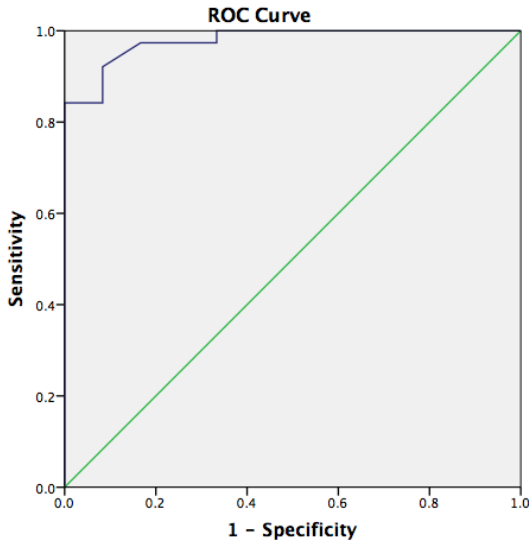






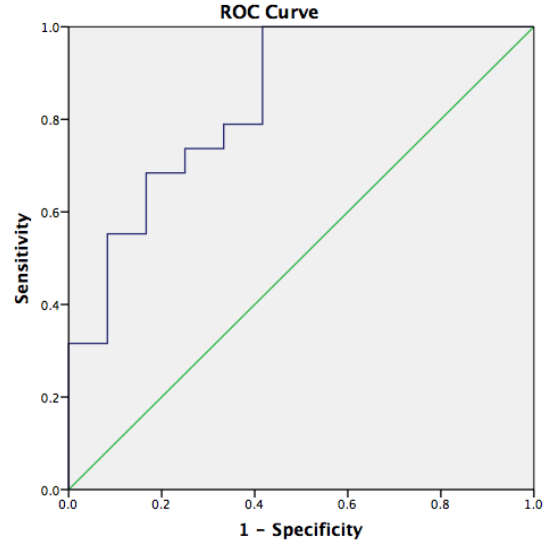
APPENDIX C: Receiver Operating Characteristics Curves from Chapter 3

Receiver Operating Characteristics curve from Chapter 3 for each isometric test direction with ‘cohort’ as the dependent (state) variable (football cohort versus comparator cohort). The diagonal line represents parity (‘no discriminative utility’, AUC = 0.50). Sensitivity = true positive rate, 1 – Specificity = inverse of false positive rate.

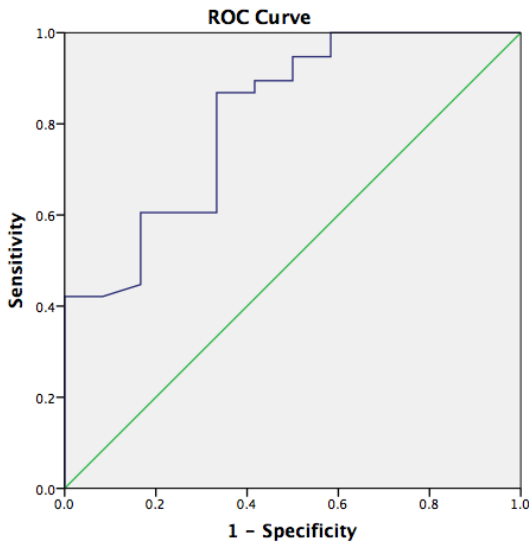


Diagonal segments are produced by ties.

Flexion

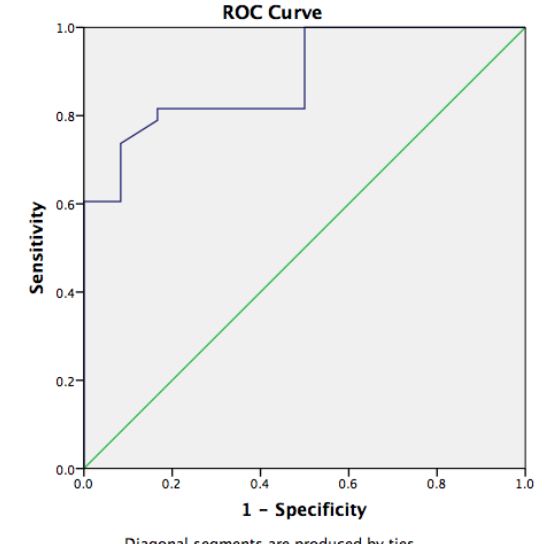


Extension



Diagonal segments are produced by ties.

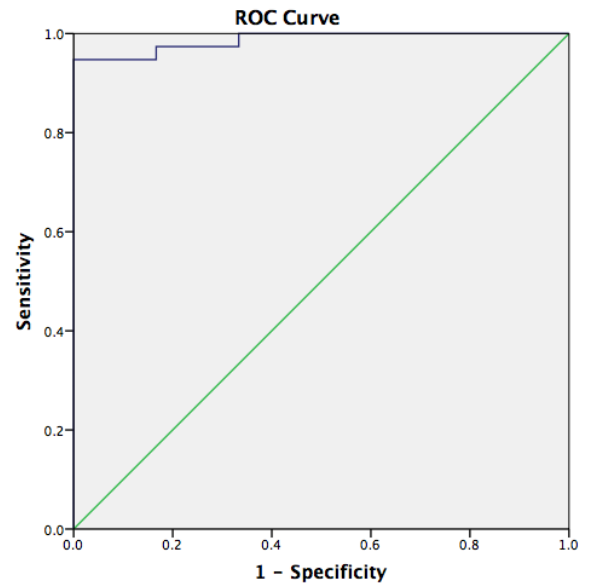
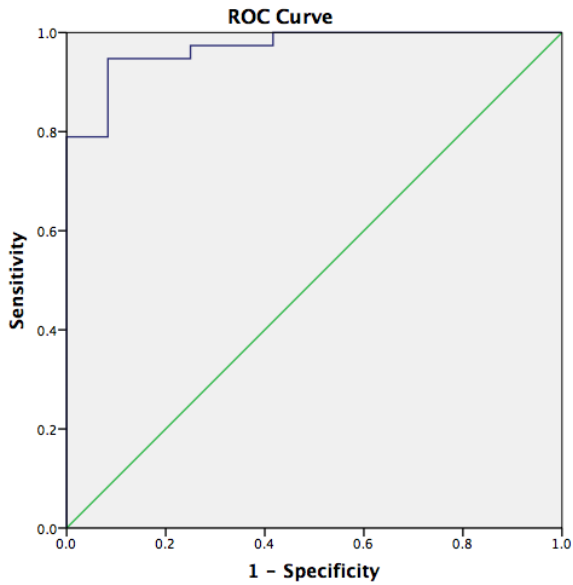
Right side-flexion



Diagonal segments are produced by ties.

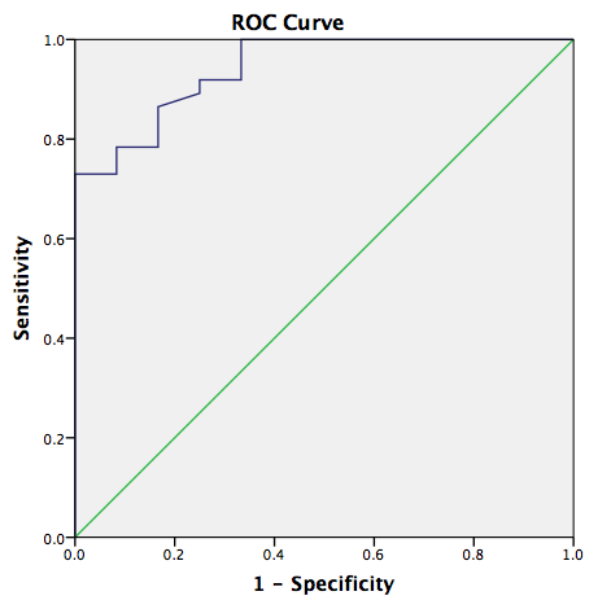
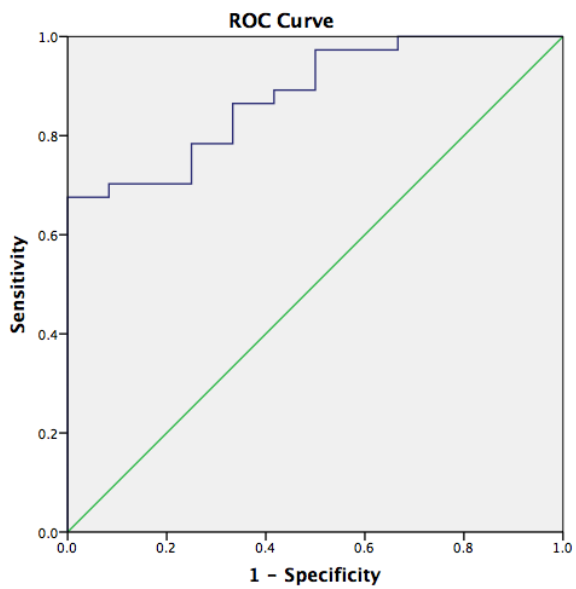
Left side-flexion

Receiver Operating Characteristics curve from Chapter 3 for each isometric test direction with ‘cohort’ as the dependent (state) variable (football cohort versus comparator cohort). The diagonal line represents parity (‘no discriminative utility’, AUC = 0.50). Sensitivity = true positive rate, $1 - \text{Specificity} = \text{inverse of false positive rate}$.



Right side-flexion/ rotation

Left side-flexion/ rotation



Diagonal segments are produced by ties.

Right rotation

Left rotation

APPENDIX D: Copyright permission and reproduction of journal article



17 December 2015

Versteegh, Theo
 Western University
 Health and Rehabilitation Sciences
 1201 Western Rd.
 London, ON
 Canada N6G 1H1
tverste@uwo.ca

RE: Your request for permission to reprint the following material:

Journal	Volume	Issue	Year	Author	Article	Pages	Copyright Holder
Physiotherapy Canada	67	1	2015	Versteegh	"Evaluating the reliability of a novel neck-strength assessment protocol for healthy adults using self-generated resistance with a hand-held dynamometer "	58-64	Canadian Physiotherapy Association

FEE: **CAD** (Amount to be paid)

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APPENDIX E: Ethics approval forms



Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Dave Walton
File Number: 103266
Review Level: Delegated
Approved Local Adult Participants: 30
Approved Local Minor Participants: 0
Protocol Title: Evaluating the reliability of a neck and upper-quadrant strength assessment protocol using self-generated closed kinetic chain resistance with a handheld dynamometer in healthy subjects
Department & Institution: Health Sciences/Physical Therapy, Western University
Sponsor:
Ethics Approval Date: December 21, 2012 **Expiry Date:** July 31, 2013
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Western University Protocol		
Other	Point-by-point response to reviewer comments	2012/12/19
Letter of Information & Consent	Revised Letter of Information	2012/12/19
Other	Revised email script	2012/12/19

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

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

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

The Chair of the HSREB is Dr. Joseph Gilbert. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.



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Use of Human Participants - Initial Ethics Approval Notice

Principal Investigator: Dr. Dave Walton

File Number:104599

Review Level:Delegated

Protocol Title:A new measurement of neck mobility and reactivity: establishing normative values, reliability, and parallel forms validity

Department & Institution:Health Sciences/Physical Therapy,Western University

Sponsor:

Ethics Approval Date:December 16, 2013 **Expiry Date:**August 31, 2014

Documents Reviewed & Approved & Documents Received for Information:

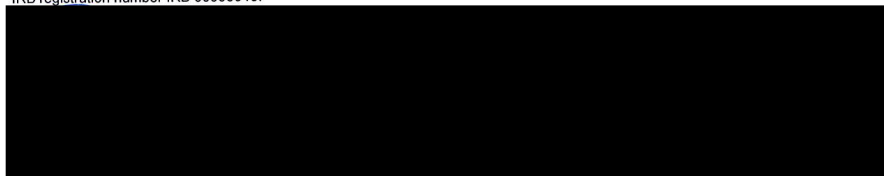
Document Name	Comments	Version Date
Other	Photo of NRUP setup	2013/10/25
Other	Pilot test: subject experiencing NRUP protocol filmed at 120 fps	2013/10/25
Other	Letter to health care provider in the event of persisting symptoms.	2013/10/25
Instruments	Form to collect any adverse outcomes, administered 24-48 hours after participation.	2013/10/25
Instruments	Intake and screening form	2013/10/25
Western University Protocol	Original-received Oct.25/13	
Letter of Information & Consent	version 1.0	2013/11/21
Other	Separate recruitment script document	2013/11/21

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

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

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

The Chair of the HSREB is Dr. Joseph Gilbert. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.



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**Western
Research**

Research Ethics

**Western University Health Science Research Ethics Board
HSREB Delegated Initial Approval Notice**

Principal Investigator: Dr. Dave Walton
Department & Institution: Health Sciences\Physical Therapy, Western University

HSREB File Number: 105388

Study Title: Evaluating the effectiveness of a new training protocol for improving neck muscle strength, reactivity and head acceleration in football players

Sponsor:

HSREB Initial Approval Date: August 01, 2014

HSREB Expiry Date: December 31, 2014

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Western University Protocol	Western University protocol clean	2014/06/25
Data Collection Form/Case Report Form	DCF clean	2014/06/25
Letter of Information & Consent	LOI clean	2014/06/25

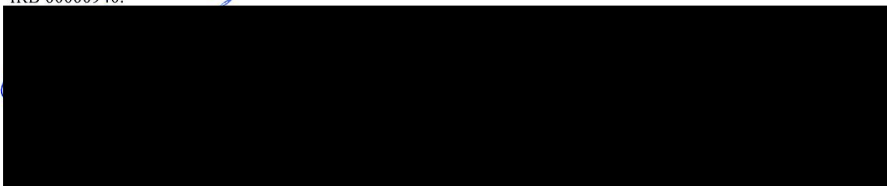
The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above named study, as of the HSREB Initial Approval Date noted above.

HSREB approval for this study remains valid until the HSREB Expiry Date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review. If an Updated Approval Notice is required prior to the HSREB Expiry Date, the Principal Investigator is responsible for completing and submitting an HSREB Updated Approval Form in a timely fashion.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice Practices (ICH E6 R1), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.



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Curriculum Vitae

Theo H. Versteegh

EDUCATION

- Doctor of Philosophy, Physical Therapy**, January 2012- (Projected Q1 2016)
Western University, London Ontario
- Master of Science, Physical Therapy**, September 2008- August 2010
The University of Western Ontario, London Ontario
- Bachelor of Science, Physical Therapy**, September 1994- June 1998
The University of Western Ontario, London, Ontario
- Diploma of Advanced Manual and Manipulative Physiotherapy**, October 2002
Canadian Physiotherapy Association Orthopaedic Division
- Certificate of Intermediate Manual and Manipulative Physiotherapy**, May 2001
Canadian Physiotherapy Association Orthopaedic division

WORK EXPERIENCE

- Fowler-Kennedy Sport Medicine Centre**, September 2008- present
London, Canada
*Private clinic, sport medicine, manual therapy, concussion management
- The Wyndham Centre**, January 2005 to January 2008
London, England
*Private clinic, manual therapy
- King Faisal Specialist Hospital and Research Center**, February 2003 to April 2004
Riyadh, Saudi Arabia
*Senior Physiotherapist outpatient orthopaedics
- Allan McGavin Sports Medicine Centre**, August 1999 to October 2002
Vancouver, BC
*Sports physiotherapy and manual therapy, private clinic
- Medical Staff, Men's and Women's Canadian National Field Hockey Team**
January 2000 to October 2002
Physiotherapy and on field coverage
- Waterloo Sport Medicine**, January 1999 to April 1999
Waterloo, Ontario
*Sport physiotherapy, private clinic

TEACHING EXPERIENCE

ROLE/POSITION	INSTITUTION /PROVIDER	COURSE	DATE
Assistant	Carol Kennedy	Concussion; What about the neck	2015
Lecturer	London Orthopaedic Division	Comprehensive concussion Management	2015
Guest Lecturer	Western University School of Physical Therapy	PT9542 Manual Therapy Cervical spine exercise	2012-2015
Teaching assistant	Western University School of Physical Therapy	PT9542 Manual Therapy	2012-2015
Teaching assistant	Western University School of Physical Therapy	PT9543 Manual Therapy	2009 - 2010

RESEARCH

Published Refereed Papers

1. **Versteegh T**, Beaudet D, Greenbaum M, Hellyer L, Tritton A, Walton D. (2015) Evaluating the reliability of a novel neck strength assessment protocol using self-generated resistance with a handheld dynamometer in healthy subjects. *Physiotherapy Canada*. 67:58-64.
2. Lindsay DM, **Versteegh TH**, Vandervoort, AA (2009) Injury prevention: avoiding one of golf's more painful hazards. *Annual Review of Golf Coaching* 3:129-148.
3. **Versteegh TH**, Vandervoort, AA, Lindsay, DM, Lynn SK (2008) Fitness, Performance and Injury Prevention Strategies for the Senior Golfer. *Annual Review of Golf Coaching* 2:199-214.
4. Overend TJ, E Thompson, **TH Versteegh**, TB Birmingham, AA Vandervoort. (2000) Cardiovascular stress associated with concentric and eccentric isokinetic exercise in young and older adults. *Journals of Gerontology: Biological Sciences*. 55:B177-B182.
5. Thompson E, **TH Versteegh**, TJ Overend, TB Birmingham, AA Vandervoort (1999) Cardiovascular responses to submaximal concentric and eccentric exercise in older adults. *Journal of Aging and Physical Activity*. 7:20-31.

Relevant Presentations

1. **Versteegh T**, (2014) The role of physiotherapy in concussion management. *See the line Concussion Research and Awareness*. London, August.
2. **Versteegh T**, (2014) Evaluating the reliability of a novel neck strength assessment protocol using self-generated resistance with handheld dynamometer in healthy subjects. *Canadian Physiotherapy Association Congress*. Edmonton, June.
3. **Versteegh T**, (2014) Assessment of Post-Concussion Syndrome: Clinical Approach from a Manual Therapist. *Rehabilitation Following Mild to Severe Traumatic Brain Injury*. Toronto, Canada January. –invited speaker.
4. **Versteegh T**, (2013) Concussion Management and the Role of Early Intervention. *Fowler-Kennedy Sports Medicine Research Rounds*. London, Canada, June.
5. **Versteegh T**, Vandervoort AA, Overend TJ, Birmingham TB, Jones I (2011) Effect of a dynamic warm-up on club-head velocity in senior golfers. *The 28th Western Homecoming Sport Medicine Symposium*, London, Canada. September.
6. **Versteegh T**, Vandervoort AA, Overend TJ, Birmingham TB, Jones I (2011) Effect of a dynamic warm-up on club-head velocity in senior golfers. *World Physical Therapy 2011*, Amsterdam, Netherlands. June.
7. **Versteegh T** (2010) Return to play: Sport specific training for the unstable shoulder. *The 27th Western Homecoming Sport Medicine Symposium*, London, Canada. October.
8. Overend TJ, **Versteegh TH**, Thompson E, Birmingham TB, Vandervoort AA.(1999) Cardiovascular stress associated with submaximal isokinetic exercise in young and older adults. *American College of Sports Medicine*, June. (poster by Overend)

Published Abstracts

1. **Versteegh T**, Vandervoort A, Overend T, Birmingham T, Jones I (2011) Effect of a dynamic warm-up on club-head velocity in senior golfers. *Physiotherapy* 97(suppl):eS1310.
2. Overend TJ, **TH Versteegh**, E Thompson, TB Birmingham, AA Vandervoort (1999) Cardiovascular stress associated with submaximal isokinetic exercise in young and older adults. *Medicine and Science in Sports and Exercise* 31(Suppl):S387.

PATENTS AND INTELLECTUAL PROPERTY

Versteegh T, Neck Muscle Exerciser and Method of Assessing Neck Muscle Performance. *United States Patent Number US 9,211,438*

HONOURS AND AWARDS

2015 Bev Padfield Clinical Research Award

London Orthopaedic Unit

2015 Smart Start seed funding

Ontario Centres of Excellence

2015 Business Innovation Access Program (BIAP)

National Research Council of Canada (NRC)

2014 Faculty of Health Science Travel Award

Faculty of Health Science, Western University

2014 HRS Travel Award

Faculty of Health and Rehabilitation Sciences,
Western University

2009 CIHR Master's Award

Canadian Institute of Health Research (CIHR)

2009 CIHR Mobility in Aging Award

Physiotherapy Foundation of Canada and CIHR

1997 Russ Jackson Award Nominee

National award granted by the Canadian Interuniversity athletic Union (C.I.A.U.) honoring academic and athletic excellence and community service

1997 Bronze "W" award recipient

Awarded to varsity athletes who have made a significant contribution to their team for three years

1997, 1994 Academic All-Canadian

C.I.A.U.

1997, 1994 Dean's Honor Role

The University of Western Ontario

1994 Nickle Family Foundation Scholarship

Nickle Family Foundation

SCHOLARLY AND PROFESSIONAL ACTIVITIES

Reviewer – Manual Therapy Journal

2015 – present

Reviewer – Physiotherapy Canada Journal

2014 - present

Spinal Trigeminal Triad

Erl Pettman, Oakville, April 2015

Third Annual Symposium: research on the Concussion Spectrum of Disorders

Canadian Sports Concussion Project, Toronto, January 2015

Vestibular Rehabilitation

Bernard Tonks, Guelph, May 2013

Sport First Responder

Canadian red Cross, London February 2013

Graded Motor Imagery Short Course

David Butler, Quebec City September 2012

Functional Movement Assessment; Implications for the Manual Therapist

Gray Cook, Quebec City September 2012

Exercise Prescription for the patient with Cervical Spine Dysfunction

Carol Kennedy, London, March 2010.

Foundation Course in Acupuncture, September 2006

British Medical Acupuncture Society

Level V Advanced Spinal Manipulation, May 2002

Carol Kennedy, Vancouver B.C.

Level IV Spinal Manipulation, December 2001

Jan Lowcock, Vancouver B.C.

Part A Preparation Course, September 2000

DOPC, Delta B.C.

E2V2- Level 2 Manual Therapy, December 1999

CPA Orthopaedic division

E2 Extremity, October 1999

May Nolan, Vancouver, BC

V2V3 Cervico-Thoracic, February 1999

Bev Padfield, London, Ontario

V2V3 Lumbar- Sacral, March 1999

Wendy Aspinall, Toronto, Ontario

Sport Physiotherapy Canada

EXTRACURRICULAR

Varsity Football Team, September 1994 to November 1997

The University of Western Ontario Mustangs

*1997 OUA All-Star Nominee, 1994 Vanier Cup Champions

2004 Assistant Football Coach

Mother Theresa High School

2001 Assistant Football Coach

University of British Columbia Thunderbirds