



Exploring the role of cervical spine endurance as a predictor of concussion risk and recovery following sports related concussion

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ABSTRACT

Background: Concussions have become a significant public health concern with rising incidence rates. Concussions have been shown to occur concurrently with neck injuries, such as whiplash-associated-disorder, therefore, understanding the role of the neck in concussions is important.

Objectives: To determine if there is a relationship between cervical muscle endurance and either concussion incidence, or concussion recovery in university athletes. Specifically, the primary aim was to investigate a relationship between pre-season deep neck flexor endurance test (DNFET) time in those who sustained an in-season injury versus those who did not. The secondary aim is to determine correlation in DNFET times and concussion recovery.

Design: Longitudinal observational study.

Methods: Pre-season DNFET was performed on university athletes. In the event of a concussion, cervical endurance and neuromuscular adaptation was re-assessed with the DNFET. Rehabilitative exercises were prescribed, as required, and DNFET was measured at subsequent treatments.

Results: There was no significant difference between pre-season DNFET times and concussion incidence ($p = 0.55$). However, there was a moderate correlation between DNFET times and concussion recovery ($R = 0.47$, $p = 0.001$) whereby DNFET times improved predictively throughout rehabilitation.

Conclusions: While no statistically significant relationship was found between DNFET and concussion incidence, a significant clinical relationship was present with recovery. The validity of the DNFET test as a means for assessing risk or measuring recovery requires additional research.

1. Introduction

Concussion incidence has become an increasing public health concern, especially in sport (Rao et al., 2017). According to the 2017 Concussion in Sport Group consensus statement, a direct or indirect force applied to the head and/or neck can result in a concussion (McCroory et al., 2017). Concussions are often sustained concurrently with neck injuries, such as whiplash-associated disorder, as a result of an external force being transmitted from the body to the head and neck or from a blow to the head (Cheever et al., 2016; Craton et al., 2017; Velikonja et al., 2017). In addition, evidence exists of cervical spine dysfunction, as a result of whiplash injury, which mimics post-concussion symptoms (Hynes and Dickey, 2006; Leddy et al., 2015; Leslie and Craton, 2013; Treleaven et al., 1994; Treleaven, 2011, 2017; Zumsteg et al., 2006). Reduced neck strength as measured by maximal

voluntary contraction, smaller neck circumference, and smaller neck to head circumference ratio have been suggested as risk factors for sustaining a concussion (Collins et al., 2014a). However, other research has found neck strength was not indicative of concussion risk (Mihalik et al., 2011). While there are no studies demonstrating a causal relationship between cervical spine injury and concussion, involvement of the cervical spine in both the injury and recovery is clinically recognized (Ellis et al., 2014; Leddy et al., 2015; Mihalik et al., 2011; Morin et al., 2016; Schneider et al., 2017, 2014; Streifer et al., 2019). It is therefore important to further examine the role of the cervical spine and its related function in concussions.

The specific mechanisms driving ‘concussion like’ symptoms from a neck injury or WAD are not well understood (Ellis et al., 2014; Morin et al., 2016). The cervical musculature is rich in proprioceptive modulators and therefore, cervical dysfunction or injury may elicit some

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symptoms consistent with concussions, including headaches, dizziness and neck pain (Boyd-clark, Briggs and Galea, 2002; Cheever et al., 2016; Ellis et al., 2014; Leddy et al., 2010). Afferent neural connections originating from the cervical spine may also be impaired by dysfunction or injury, thus affecting vestibular, visual and/or somatosensory functioning (Cheever et al., 2016; Kristjansson and Treleaven, 2009; Marshall et al., 2015; Treleaven et al., 2011). More specifically, cervical spine dysfunction may result in impairment to several associated reflexes including the cervico-ocular reflex, cervico-colic reflex, and tonic neck reflex; precipitating symptoms of dizziness, unsteadiness or even visual symptoms (Treleaven et al., 2011; Treleaven, 2008). Visual disturbances in WAD, highlight the complexities of the cervical spine in head and neck trauma (Ischebeck et al., 2016; Treleaven et al., 2011). Consequently, evaluating neck endurance along with other cervical spine tests, such as smooth pursuit neck torsion test and somatosensory tests, may assist the clinician in determining the extent of cervical involvement in concussion symptomatology and aid in categorizing the diagnosis further (Collins et al., 2014b; Craton et al., 2017; Ellis et al., 2014; Marshall et al., 2015).

The deep neck flexor endurance test (DNFET) is a clinically reliable and practical test to evaluate a patient's cervical spine endurance (Domenech et al., 2011; Grimmer, 1994; Harris et al., 2005; Jarman et al., 2017; Juul et al., 2013). The DNFET has strong intra-rater reliability (de Koning et al., 2008; Harris et al., 2005; Martins et al., 2018; Olson et al., 2006). Although other measures of cervical spine endurance exist, such as the cranio-cervical flexion test (CCFT), the DNFET is a non-instrumented test which makes it favourable to use in many situations. The CCFT requires an air-filled pressure sensor to measure changes in DNF activation and a longer five stage protocol, which is more challenging to administer (Jull, O'Leary and Falla, 2008). It is therefore important to assess the effectiveness of the DNFET in identifying cervical endurance dysfunction, and the associated neuromuscular adaptation, in the context of a concussive injury, to determine if this dysfunction relates to concussion risk and recovery. In a rehabilitative setting, the neuromuscular adaptation component of the DNFET may also be of significant value, as it has been accepted that neuromuscular improvements (rather than physiological change) contribute significantly to initial strength gains in training programs (Gabriel et al., 2006). Neurological adaptations have been reported to be manifested by alterations in cortical activity, motor unit function, and muscle force (Hedayatpour and Falla, 2015). Accordingly, the DNFET may be beneficial to use in concussion rehabilitation for measuring improvements in endurance associated with neuromuscular adaptation and improved recruitment of the cervical flexors.

We found no existing evidence where the DNFET was used as a tool to either predict the risk of sustaining a concussion or to assess the recovery from a concussion. There is an ongoing need to minimize concussion risk and to identify additional risk factors which may aid in prevention. While the primary purpose of our study was to determine if there was a relationship between pre-season DNFET times of uninjured athletes (UA) and injured athletes (IA), a secondary purpose was to determine if there was a correlation between DNFET times and recovery progress, as measured by return-to-play (RTP) stage, throughout rehabilitation with the IPM team.

2. Materials and methods

2.1. Participants

All procedures were approved by the University Research Ethics Board and all participants included in this study gave informed consent for use of their data. Any athletes who did not consent were still pre-season tested and treated the IPM team if they sustained a concussion but their data was excluded. All athletes were also free to access other medical care in the case of an injury. Only athletes seen by the IPM team were included in this study. One hundred thirty university varsity

athletes, 68 females and 62 males, from the men's and women's hockey, soccer, and basketball teams were followed throughout their respective seasons. Each team underwent pre-season testing and concussion education with the IPM team. Upon sustaining a suspected concussion, athletes were assessed by the IPM team to determine if a clinical diagnosis of concussion was warranted. If a diagnosis was made, athletes followed up with the IPM team and completed a graduated RTP and return-to-learn protocol consistent with the 2017 Concussion in Sport Group consensus statement (McCroly et al., 2017).

2.2. IPM team

An inter-professional management (IPM) team coordinated and managed concussion care of university athletes including pre-season testing, education and post-injury care. The IPM team, who all have focused clinical practices in interdisciplinary concussion treatment, consists of a medical doctor, a nurse practitioner, a chiropractic clinical sciences specialist (CCSS), a registered kinesiologist and a clinical coordinator. The medical doctor and nurse practitioner were primarily responsible for diagnosis of a concussion and assessment of cognitive and visual function. The CCSS was responsible for somatic and cervicogenic assessments. Graded exercise testing and aerobic exercise supervision was the responsibility of the registered kinesiologist.

2.3. DNFET protocol

The DNFET was used at pre-season testing and, in the case of a concussion, at initial assessments and follow up appointments, as appropriate. The test was conducted by the CCSS at initial assessment of a concussed athlete and throughout rehabilitation. Pre-season DNFET was conducted by the team's research assistant, trained by the CCSS. The DNFET protocol was based on the procedure employed by Harris et al. (2005). The test was explained to the athletes and all were informed they could withdraw their consent to have their data included in the study at any time. The athlete was instructed to lay supine on a padded bench with their hands at their side and head resting on the bench keeping the cervical muscles relaxed. They were then asked to assume a crook-lying position by retracting their chin and tilting their head up until the examiner could fit two fingers between their head and the table. The athlete was then allowed to relax and was advised that this would be the position they were to maintain throughout the test for a span of up to 45 s during pre-season testing, or until the proper position could not be maintained. Several studies indicate average DNFET in healthy populations are between 21 and 39 s, therefore, the 45 s cut off was expected to still reveal the effects of lower DNFET times (Domenech et al., 2011; Ghamkhar et al., 2018; Harris et al., 2005; Jarman et al., 2017; Olson et al., 2006). The test was terminated if the examiner observed excessive tremors of the head or cervical musculature, a loss of head position (characterized by increased cervical flexion), a loss of chin retraction or if the athlete experienced a significant increase in neck pain or headache during the test. The test duration was measured in seconds with the examiner using a stopwatch. The same procedure was followed at initial concussion assessments and follow-up appointments.

2.4. Pre-season testing

Pre-season testing was conducted on all athletes and concussion education was provided by the IPM team and members of the research team. Concussion education consisted of informing athletes about symptom presentation, red flag symptoms, the importance of reporting symptoms and access to care. Athletes were systematically evaluated on their smooth pursuits, convergence, accommodation reflex, vestibular-ocular reflex, cervico-ocular reflex, and neck endurance as measured by DNFET, as well as balance and reaction time testing.

2.5. Post-concussion care

Upon sustaining a suspected concussion, athletes were assessed by the IPM team within 5 days and a clinical diagnosis was made. Athletes were also assigned clinically relevant features, contingent upon the results of clinical tests and their dominant symptoms. Cervical rehabilitation exercises were prescribed and progress was managed using a pragmatic approach based on the CCSS clinical judgement. Examples of prescribed exercises include, eccentric chin tucks and sub-maximal DNFET holds. Cervical endurance and neuromuscular adaptation was tested at each treatment session using the DNFET until the athlete was able to maintain the DNFET position for 60 s at 2 consecutive treatment sessions.

2.6. Data analysis

Data analysis was collected quantitatively. A Shapiro-Wilk test concluded that DNFET scores were not normally distributed, and could not be successfully transformed, therefore non-parametric testing was conducted. To determine if pre-season cervical endurance was a measure of the risk of sustaining a concussion, DNFET times were compared amongst groups within the sample. Times were organized and tested in three different ways; as 1) dichotomous variables separated by the approximate population mean of 30 s (< 30 , ≥ 30 s), 2) interval variables where times were divided into six groups (< 11 , 11–15, 16–20, 21–25, 26–30, > 30 s), and 3) continuous variables of absolute time (to the nearest second). For each category, the scores of UA and IA were compared across the entire sample and across biological sexes using a two-sample Wilcoxon rank sum test.

To determine if there was a relationship between the improvement of cervical endurance and neuromuscular adaptation, compared to recovery stage during rehabilitation, a Pearson's correlation test was conducted. A Shapiro-Wilk test for normality of data distribution was also performed and the data was found to be not normally distributed. Cervical endurance values were measured by DNFET times (absolute time, to the nearest second) and recovery stage was measured by (RTP) stage, as assigned to the athlete by the IPM team.

All statistical analyses was conducted using R (v. 3.2.3) (Team RC, 2014).

3. Results

Twelve of the 130 athletes who were pre-season tested sustained a concussion, 6 females and 6 males. Five additional male athletes sustained a concussion and were included in the study for recovery progression but did not have pre-season data.

Pre-season DNFET scores of uninjured (UA) and injured (IA) athletes were compared in several different ways: in absolute seconds, six smaller intervals, and two intervals across the entire sample for both sexes. A 2.6 s difference between means was found, when comparing the entire sample in absolute time, with the IA group having the lower average score. The mean score of UA was 32.18 s (SD = 9.85 s) and IA was 29.58 s (SD = 10.12 s). The median score of UA was 30 s and IA was 28 s. No statistical significance was found when comparing scores from absolute times ($p = 0.55$) (Fig. 1: DNFE & Concussion Incidence), six smaller intervals ($p = 0.50$) or two large intervals ($p = 0.49$) across the sample. The results remained insignificant when comparing absolute times of females ($p = 0.84$) and males ($p = 0.55$) independently one another (Fig. 2: Female incidence; Fig. 3: Male incidence). In females, a 2.32 s difference in means was found, with IA possessing a mean time of 29.17 s (SD = 11.72 s) and UA possessing a mean time of 31.49 s (SD = 9.51 s). In males, a 2.93 s difference in means was found, with IA possessing a mean time of 30.00 s (SD = 9.36 s) and UA possessing a mean time of 32.93 s (SD = 10.24 s).

We also compared the progression of DNFET scores to RTP stage progression throughout rehabilitation by a Pearson's correlation. A

moderate but significant positive correlation was found ($R^2 = 0.474$, $P = 0.001$), indicating that cervical endurance and neuromuscular adaptation, as measured by the DNFET, tends to improve predictively throughout rehabilitation (Fig. 4: DNFE & RTP Stages).

4. Discussion

The primary purpose of our study was to determine if there was a relationship between DNFET times and concussion incidence in a varsity athletic population. We postulated that lower pre-season DNFET times would be associated with a higher incidence of concussions, indicating that poor cervical flexor endurance would be predictive of the risk of sustaining a concussion. Our results demonstrated no statistical difference between pre-season DNFET times and concussion incidence, suggesting either that reduced cervical endurance is not related to risk of sustaining a concussion or the DNFET is not sensitive enough to detect it. One explanation is the large variance in DNFET times within the tested population. Our results are comparable to several studies establishing normative data which also feature a high degree of variance (Domenech et al., 2011; Jarman et al., 2017; Martins et al., 2018). In addition, differences between sexes, with men exhibiting longer times than females, were consistent with these previous studies. The high degree of variability, compounded by the small sample size of IA ($n = 12$) compared to UA ($n = 118$) may also have contributed to the lack of statistical significance in our study due to a reduction in the power of our analysis.

Despite our results lacking significance, the IA pre-season scores did tend to be lower than the UA scores. These results are consistent with previous literature comparing individuals with cervical pain and dysfunction to those without, where those with cervical pain and dysfunction tend to have reduced cervical endurance and DNF activity (Falla et al., 2004; Harris et al., 2005). We speculate that this dysfunction may serve as a risk factor for athletes' vulnerability for incurring a concussion as their ability to react and stabilize their head, and resist transmission of external forces may be compromised. Furthermore, in a study comparing cervical endurance, using the DNFET, to proprioception, subjects with pain tended to perform worse on the DNFE, and mild proprioceptive abnormalities, suggesting a potential relationship between cervical endurance and dysfunction. However, as in this study, the difference was not significant and high levels of variance were noted (Ghamkhar et al., 2018). Likewise, the CCFT revealed patients with both chronic and acute neck pain from WAD, exhibited altered motor patterns of activation, with superficial cervical muscles being recruited more in patients with pain than those without (Jull et al., 2004). Electromyography has confirmed that patients with neck pain who exhibit increased superficial cervical flexor activation also show reduced DNF activation (Jull and Falla, 2016). All of this, taken together, suggests some interaction between cervical endurance and neuromuscular adaptation but using cervical endurance as a predictor of risk for sustaining a concussion is a challenge because it is not known what amount of additional endurance time may be protective and/or may be indicative of recovery. Nor is it known how much or how quickly training endurance might elicit neuromuscular adaptations.

Although we did not find differences in concussion risk between athletes with respect to cervical endurance, it has been found that neck strength may reduce risk (Collins et al., 2014a). However, these results appear mixed, where no additional concussion risk is found in those with reduced neck strength (Mihalik et al., 2011). In both of these studies, dynamometry measured maximal voluntary contraction as the determinant of neck strength. Evidently, each test measures different components of cervical musculature; however, the strength of the entire muscle group is important, especially in concussive injury, as all muscles will need to be recruited for head stabilization. While dynamometry demonstrates increased reliability in comparison to the DNFET it is unable to isolate specific muscle groups. Furthermore, in a rehabilitative setting, dynamometry also poses a potential obstacle, as

patients may not provide a complete effort due to fear of exacerbating their injury (O'Leary et al., 2007).

Situational exposure may be another factor contributing to the insignificant relationship between DNFET times and concussion incidence. While all athletes rostered on a team were pre-season tested, there was no consideration for their playing time, position, sport, or other factors that may have reduced their playing time (injury or suspension). For example, a goaltender may not have the same situational risk as forward or defense despite differences in DNFET times. In the NHL, it was found that players at the forward position were more likely to sustain a concussion than those on defence or goaltenders (Hutchison et al., 2015).

The secondary purpose of our study was to determine if cervical endurance and neuromuscular adaptation, as measured by the DNFET, was related to recovery, quantified by RTP stage. We postulated that improvement in DNFET times would be positively correlated to recovery progress. Our results showed a positive correlation with strong significance ($R^2 = 0.47$, $p = 0.001$). In the context of the clinically relevant features of the concussion, improvement of cervical endurance and neuromuscular adaptation may be an objective indicator of recovery progress. If a cervical spine related clinically relevant feature is an important characteristic of the injury sequelae, as pointed out by a recent study conducted by Ellis et al. (2018), then our results suggest using cervical endurance and neuromuscular adaptation as a measure of recovery may be useful.

It is unclear precisely what the improvement in cervical endurance and neuromuscular adaptation is a result of. Exercises were prescribed to promote neuromuscular adaptation throughout treatment; however, exercise adherence is self-reported from the patient. DNFET times have been shown to improve with subsequent trials, even without practice (Grimmer, 1994; Olson et al., 2006). This may be the result of motor learning, as times could improve throughout rehabilitation without completing prescribed exercises. If the patient did not complete the prescribed exercises, their cervical endurance and neuromuscular improvement would be a function of time rather than treatment and exercise prescription. These results indicate more research evaluating controlled exercise training groups should be explored.

Our study has several limitations. The sample size of injured athletes was small. The entire sample population was quite uniform in that it was comprised of university varsity athletes, representing only a small portion of society in both age and physical activity level. However, other literature has found little to no difference in DNFET times between varying activity levels (Domenech et al., 2011). Reports of pre-existing neck pain were also not included in pre-season testing, which would have been beneficial to further differentiate healthy subjects from those who may be at higher risk for neck-related or concussive injuries, as neck pain has been shown to be related to weakness (Jull et al., 2008; Olson et al., 2006). Another significant confounding risk factor not taken into consideration was data of situational exposure, which includes playing time and position. More playing time would result in increased situational exposure for sustaining a concussion. Certain positions have also been shown to be at greater risk than others (Pellman et al., 2004; Hutchison et al., 2015). Additionally, factors such as ethnicity, body habitus and age were not accounted for in our analysis.

There are also two major limitations to the DNFET. First, the DNFET consistently yields high levels of variance, typically between 9 and 45 s (Edmondston et al., 2008; Jarman et al., 2017; Parazza et al., 2014; Piper, 2009; Placzek et al., 1999). Our variance was congruent with these results (UA = 9.85 s; IA = 10.12 s). The second limitation is that the DNFET, though reliable and valid for testing cervical endurance, does not entirely isolate the DNF muscles as effectively as the CCFT (O'Leary et al., 2007). However, the DNFET may be sufficient assuming all cervical muscles are recruited to stabilize the head immediately following the application of an external force, such as those incurred in concussive injuries. Therefore, evaluating neuromuscular coordination

and endurance of the both the superficial and DNF muscles synergistically may be beneficial when assessing risk. In addition, the strong inter-rater reliability of the DNFET (de Koning et al., 2008; Harris et al., 2005; Martins et al., 2018; Olson et al., 2006) and lack of instrumentation enhances its usefulness for pre-season testing.

The association between cervical spine and concussion incidence seems poorly understood, demonstrating a need for further research. Much of the literature has examined the influence of cervical strength on concussion risk, yet other concomitant cervical components, such as proprioception, endurance, posture, pain, and stability may also influence cervical function (Domenech et al., 2011; Hildenbrand and Vasavada, 2013; Jull et al., 2004; Olson et al., 2006; Panjabi, 2006; Streifer et al., 2019). Due to the influence of these interdependent components on cervical spine function, future research should focus on these interactions in order to elucidate the influence they may have on concussion risk. Furthermore, there is a need for valid and reliable tests to measure cervical spine function, both when assessing pre-morbid risk and recovery from a concussion, thus there may be value in comparing pre-season values between the CCFT and DNFET. It may also be prudent to investigate the influence of pre-morbid cervical function on markers of concussion severity, such as symptom reports, or time in treatment. Our recommendation for future research is also concurrent with a recent review on the role of the cervical spine in concussions (Streifer et al., 2019).

5. Conclusions

Our research evaluated the relationship between cervical endurance, as measured by the DNFET, and risk of sustaining a concussion. We also examined DNFET performance as a measure of recovery progress during rehabilitation of a concussion. We found that cervical endurance was not predictive of increased risk of sustaining a concussion. However, a possible relationship may exist, as injured athletes had slightly lower pre-season DNFET times on average. DNFET scores were also found to be positively correlated with an athlete's RTP progression and may be used as an objective indicator of athlete recovery, depending on the clinically relevant features of their concussion. Certainly the statistical significance of the correlation between cervical endurance and neuromuscular adaptation with concussion recovery also warrants further research.

Ethical conduct of research

The authors obtained ethical approval for this study from the University Research Ethics Board. All participants were informed of voluntary participation without consequence and those included gave informed consent.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.msksp.2019.04.002>.

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