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Characterization of cervical neuromuscular response to head-neck perturbation in active young adults

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ABSTRACT

Background: The majority of studies examining the role of cervical muscles on head-neck kinematics focused on musculoskeletal attributes (e.g. strength). Cervical neuromuscular response to perturbation may represent a divergent construct that has not been examined under various perturbation conditions. This study examined the association between cervical musculoskeletal attributes and cervical neuromuscular response of the sternocleidomastoid (SCM) to perturbation. Furthermore, this study examined the effect of anticipation and preload on the SCM neuromuscular response.

Methods: Nineteen participants completed measurement of SCM muscle size, cervical flexion maximal voluntary isometric contraction, and the neuromuscular response of the SCM to cervical perturbation. Cervical perturbation was delivered by dropping a 1.59 kg mass from a loading apparatus. The impulsive load was delivered under four conditions: (1) Anticipated perturbation with no preload (A-NP), (2) Unanticipated perturbation with no preload (U-NP), (3) Anticipated perturbation with preload (A-P), and (4) Unanticipated perturbation with preload (U-P).

Results: None of the cervical musculoskeletal attributes were correlated with the SCM cervical neuromuscular response. This study demonstrated significant effect of preloading and anticipation on baseline EMG amplitude and EMG onset latency for the SCM. Furthermore, there was a significant effect of preloading on average EMG response amplitude for the SCM.

Discussion: The findings of this study indicate that cervical neuromuscular response of the SCM is different from musculoskeletal attributes and is influenced by perturbation conditions. These findings provide conceptual support to examine the neuromuscular response of the SCM in mitigating head-neck kinematics.

1. Introduction

With an estimated 3.8 million sports and recreation-related mild traumatic brain injuries (i.e. concussions) in the U.S every year, and reports that concussion incidence continues to rise (Zhang et al., 2016), the Centers for Disease Control and Prevention (CDC) have declared concussion a silent epidemic (Langlois et al., 2004). A better understanding of concussion risk factors is needed to develop strategies to reduce their severity and incidence (Emery et al., 2017).

Cervical musculoskeletal attributes may represent a modifiable risk factor for concussion (Collins et al., 2014; Hrysomallis, 2016). Furthermore, there are biomechanical and clinical similarities between sport-related concussion and whiplash injuries (Elkin et al., 2016). As such, investigators have examined the role of cervical muscle attributes in reducing head impact and its implications on concussion risk, with inconsistent results (Collins et al., 2014; Eckner et al., 2014; Schmidt et al., 2014).

Most studies examining the role of cervical musculoskeletal attributes on dynamic responses of the head-neck complex have assessed neck circumference and neck muscle strength (Eckner et al., 2014; Tierney et al., 2005). The effects of strength training on dynamic head responses have been inconclusive. While some epidemiological investigations reported that strength gains did not correspond with changes to dynamic stabilization of the head after impulsive loads (Lisman et al., 2012; Mansell et al., 2005). Collins et al. reported that an increase in neck strength was associated with reduced risk of concussion (Collins et al., 2014).

Similarly, laboratory studies investigating the role of cervical

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strength in mitigating head kinematics have been inconsistent. For example, Eckner et al. reported that greater neck strength attenuated measures of linear and angular head acceleration after simulated impact in a lab environment (Eckner et al., 2014). However, Schmidt et al. and Mihalik et al. reported that greater neck strength did not mitigate the head impact severity in the field over a season of play (Mihalik et al., 2011; Schmidt et al., 2014).

The lack of consistent relationships between cervical musculoskeletal attributes (e.g. strength) and dynamic head-neck responses may be due to the failure to account for other factors affecting the dynamic response of head-neck segment. Neuromuscular responses to perturbation may represent a different construct from cervical musculoskeletal attributes. However, the associations between cervical neuromuscular responses to perturbation and cervical musculoskeletal attributes have not been fully explored.

It has been suggested that cervical neuromuscular attributes such as a shorter muscle onset latency and a greater amplitude can increase the effective head-neck stiffness and play a protective role in mitigating impact severity (Gilchrist et al., 2017; Schmidt et al., 2014). Similarly, patients with neck pain demonstrated an altered cervical neuromuscular response to perturbation which may potentially expose them to subsequent injuries (Falla et al., 2004a; Falla et al., 2004b; Falla et al., 2011).

Neuromuscular response to perturbation is influenced by the level of pre-existing muscle activation prior to the perturbation, and whether individuals anticipate the impulsive loads or not (Bedingham et al., 1984; Eckner et al., 2014; Kuramochi et al., 2004; Milosevic et al., 2016; Reid et al., 1981; Shinya et al., 2016). However, the effects of anticipation and pre-perturbation muscle activation have been examined in isolation. Because athletes sustain impulsive loads under various combinations of anticipation and pre-perturbation muscle activation, characterization of neuromuscular responses under different conditions would provide insights into neuromuscular response to perturbation under conditions relevant to sport. Moreover, characterization of neuromuscular response under these conditions provide a foundation to examine its role in mitigating the head-neck kinematics and in concussion risk.

The first goal of this study is to examine the associations between cervical musculoskeletal attributes and cervical neuromuscular attributes during impulsive loading to the head under different anticipation and preload conditions. We hypothesize that cervical musculoskeletal attributes will co-vary with one another, but will be independent from neuromuscular responses. The second goal is to quantify the effects of preload and anticipation on neuromuscular responses. We hypothesize that load anticipation and muscle pre-activation (via pre-loading) will affect neuromuscular responses.

Approximately 58% of concussive impacts occur in the sagittal plane (Rowson et al., 2012), with the majority being backward directed forces applied to the front of the helmet or face mask (Pellman et al., 2003a; Pellman et al., 2003b; Viano et al., 2005). Therefore, we sought to examine the cervical neuromuscular response to forced extension. The neuromuscular response of the sternocleidomastoid was examined because it accounts for 69% of force generating ability to resist forced extension (Vasavada et al., 1998).

2. Material and Methods

2.1. Participants

Nineteen recreationally active young adults (9 males/10 females), between 18 and 25 years of age, were recruited through informational flyers posted on the campus of the primary author's institution. We operationally defined recreationally active individuals as those who participate in at least 8 h/week of any sport or exercise activities. Participants were screened for possible neck pain and associated impairments using the Neck Disability Index (NDI) (Vernon et al., 1991), and were excluded if they scored $\geq 10\%$ on the NDI (MacDermid et al., 2009). Participants were also excluded if they reported any history of chronic medical conditions, neurological or musculoskeletal problems, any history of concussion or neck injury. This study protocol was Approved by the Institutional Review Board at the primary author's institution and participants provided informed consent prior to their participation in the study.

2.2. Cervical musculoskeletal attributes

2.2.1. Neck circumference and Sternocleidomastoid (SCM) physiological cross-sectional area (PCSA)

Neck circumference was measured just above the thyroid cartilage using a retractable cloth tape measure with participants lying in a supine position with the head and neck in neutral and arms resting at their sides. The PCSA of the right SCM muscle was measured at the midpoint between the inferior aspect of the mastoid process and the clavicular margin (Arts et al., 2010), using ultrasound imaging (Treason 3200, Treason Inc., Burlington, MA). Three consecutive measures were obtained using a 6–1 MHz linear array transducer with a 4.4 cm footprint probe. The transducer was placed perpendicular to muscle fiber orientations. The average of three measurements was used in the analysis. An Acoustic standoff pad was used to increase the field of view (FOV) if the SCM was too large relative to the size of the transducer and could not be captured in a single frame (Keshwani et al., 2015).

2.2.2. Maximal isometric strength and rate of force development

After the skin was lightly abraded, and cleaned with isopropyl alcohol, wireless EMG electrodes (Noraxon Inc, Scottsdale, AR) were placed over the right sternocleidomastoid muscle, parallel to the muscle fibers at one third of the distance between the mastoid process and the sternal notch (Almosnino et al., 2009; Falla et al., 2002). These EMG electrodes were used to obtain the maximum EMG amplitude (EMG_{MAX}) for each participant during forceful flexion. The EMG_{MAX} was used to normalize the EMG amplitudes collected during perturbation.

Customized headgear was fit snuggly on the participants, and a uniaxial force transducer (Model #SML-100, Noraxon Inc, Scottsdale, AZ) was attached in series with a steel bar that connected the force transducer to the wall (Fig. 1). Maximum voluntary isometric contraction (MVIC) was measured in Newtons as participants pulled in flexion "as quickly and as forcefully as possible" and maintained the force for three seconds. Participants were instructed to avoid using their abdominal and torso muscles, avoid grasping onto the chair with their hands and avoid pushing on the ground with their feet. Participants were allowed to practice until they demonstrated proper technique. They were provided with feedback during practice trial to assist them in mastering the correct technique. During testing, a research assistant observed their performance to ensure the proper technique. If a trial was not conducted properly, it was discarded and repeated. Three MVIC

Fig. 1. Participant position for maximum voluntary isometric testing.