Journal of Electromyography and Kinesiology 23 (2013) 1206–1214

Contents lists available at SciVerse ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Electromyography responses of pediatric and young adult volunteers in low-speed frontal impacts

Emily A. Mathews [a,b], Sriram Balasubramanian [a,b,*], Thomas Seacrist [b], Matthew R. Maltese [c], Robert Sterner [d], Kristy B. Arbogast [b]

[a] School of Biomedical Engineering, Science and Health Systems, Drexel University, 3120 Market St., Philadelphia, PA 19104, USA
[b] Center for Injury Research and Prevention, The Children's Hospital of Philadelphia, 3535 Market St., Suite 1150, Philadelphia, PA 19104, USA
[c] Department of Anesthesiology and Critical Care Medicine, The Children's Hospital of Philadelphia, 34th St. and Civic Center Blvd., ARC Rm 716F, Philadelphia, PA 19104, USA
[d] Department of Health and Exercise Science, Rowan University, 201 Mullica Hill Rd., Glassboro, NJ 08028, USA

ARTICLE INFO

Article history:
Received 11 June 2012
Received in revised form 18 May 2013
Accepted 17 June 2013

Keywords:
Biomechanics
Electromyography
Pediatric
Dynamic loading

ABSTRACT

No electromyography (EMG) responses data exist of children exposed to dynamic impacts similar to automotive crashes, thereby, limiting active musculature representation in computational occupant biomechanics models. This study measured the surface EMG responses of three neck, one torso and one lower extremity muscles during low-speed frontal impact sled tests (average maximum acceleration: 3.8 g; rise time: 58.2 ms) performed on seated, restrained pediatric ($n = 11$, 8–14 years) and young adult ($n = 9$, 18–30 years) male subjects. The timing and magnitude of the EMG responses were compared between the two age groups. Two normalization techniques were separately implemented and evaluated: maximum voluntary EMG (MVE) and neck cross-sectional area (CSA). The MVE-normalized EMG data indicated a positive correlation with age in the rectus femoris for EMG latency; there was no correlation with age for peak EMG amplitudes for the evaluated muscles. The cervical paraspinous exhibited shorter latencies compared with the other muscles (2–143 ms). Overall, the erector spinae and rectus femoris peak amplitudes were relatively small. Neck CSA-normalized peak EMG amplitudes negatively correlated with age for the cervical paraspinous and sternocleidomastoid. These data can be useful to incorporate active musculature in computational models, though it may not need to be age-specific in low-speed loading environments.

1. Introduction

According to the US Centers for Disease Control, the leading cause of death for individuals 5–34 years is motor vehicle collisions (CDC, 2010). Computational modeling serves as a tool to examine occupant motion during automobile collisions and determine injury causation in an effort to design safety countermeasures. The role of muscle activation in occupant kinematics may also help accurately determine injury causation.

Currently, improvements in vehicle safety are achieved through analyses of post-mortem human subjects and anthropomorphic test device (ATD) kinematics, which do not account for the effect of active musculature on occupant kinematics. Several studies have evaluated muscle activity of adult volunteers in response to dynamic events. Low-speed frontal impact tests on adult volunteers showed considerable influence of muscle response on the occupant kinematics, in that occupants who were tensed prior to the impact demonstrated more limited excursions than when relaxed pre-impact (Ejima et al., 2007). Choi et al. (2005) quantified the muscle tensing activity of adult occupants during pre-impact bracing. These results were further used to validate computational human models with simulated muscle activity (Ejima et al., 2009; Choi et al., 2005). Additionally, Kumar et al. (2003, 2006) examined the effect of seat belt use on cervical muscle activity in response to multi-directional loading at varying magnitudes of acceleration and found that with increasing acceleration, the time to onset of electromyography (EMG) decreased. In a study to evaluate the cervical muscle activity of volunteers in low-speed rear impacts, Magnusson et al. (1999) concluded that the onset times of the cervical muscles could influence injury patterns. They also determined that the distance between the muscle and the spinal axis influences the muscle's reaction time. Bose and Crandall (2008) used musculoskeletal modeling to study the role of bracing on kinematics of restrained occupants, demonstrating the utility of measuring muscle activity during dynamic events to incorporate muscle response in models optimizing adaptive restraint systems. They found that the occupant injury outcomes, as well as their interaction with the restraint system, were sensitive to pre-impact

* Corresponding author. Address: 3120 Market St., 7-718, Philadelphia, PA 19104, USA. Tel.: +1 215 571 3738; fax: +1 215 895 4983
E-mail address: sri.bala@drexel.edu (S. Balasubramanian).

1050-6411/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jelekin.2013.06.010

bracing by the occupant. Studies on occupant awareness showed that unaware subjects had increased excursion than those with some level of awareness of the imminent perturbation (Siegmund et al., 2003; Kumar et al., 2000, 2002).

The aforementioned studies were conducted on adult subjects; to our knowledge, similar data do not exist in the pediatric population. There is also a dearth of information on the effect of age on the temporal nature of muscle activation during a dynamic event. Therefore, the objective of the current study was to measure the EMG responses of the neck, torso and lower extremity in children during a low-speed frontal impact and compare those to similar data from young adults. We hypothesize that under similar crash conditions there will be an age effect for muscle response timing and amplitude between children and young adults.

2. Methods

This study protocol was reviewed and approved by the Institutional Review Boards at The Children's Hospital of Philadelphia, Philadelphia, PA and Rowan University, Glassboro, NJ. Informed consent/assent was obtained from all the participants of this study.

2.1. Human volunteer instrumentation, testing, and data processing

A comprehensive description of the testing method can be found in Arbogast et al. (2009). Briefly, low-speed frontal sled tests were conducted using 20 male human volunteers (11 pediatric subjects: 8–14 years old, nine young–adult subjects: 18–30 years old). Gender-specific differences in neck flexibility have been observed in the passive cervical range of motion in male and female children and adults (Seacrist et al., 2012). Therefore, only male subjects were recruited. All subjects were between 5th and 95th percentile for their age-appropriate height, weight and body mass index (Centers for Disease Control, 2000; NHANES, 1994). Subjects with existing neurologic, orthopedic, genetic, or neuromuscular conditions, any previous injury or abnormal pathology relating to the head, neck or spine were excluded from the study.

A pneumatically actuated, hydraulically controlled low-speed acceleration volunteer sled (Fig. 1a) consisting of a moving platform with a low back padded seat, lap-shoulder belt and an adjustable foot rest was used to subject restrained human volunteers to a sub-injurious, low-speed frontal crash pulse. Volunteers were propelled backward and then rapidly decelerated, simulating a low-speed frontal crash. The maximum linear acceleration was 25% below the maximum acceleration measured during an amusement park bumper car ride (4.3 g in 61.9 ms) (Arbogast et al., 2009). Age-based differences in kinematic response have been previously reported (Arbogast et al., 2009) and are not the focus of this paper.

Surface EMG measurements were obtained for all trials. Prior to sEMG electrode placement, the subject's skin was cleaned by applying Skin Prepping Gel (NUPREP, Weaver and Co., Aurora, CO). Disposable, self-adhesive Ag/AgCl bipolar surface EMG disk electrodes (10 mm diameter, 20 mm inter-electrode distance measured center-to-center) (Noraxon, Inc., Scottsdale, AZ) were placed bilaterally (left-L, right-R) on the skin over the mid-belly of key muscle groups surrounding the neck (Sternocleidomastoid (SCM), Cervical Paraspinous (CP) and Upper Trapezius (UT)), lower torso (Erector Spinae (ES)), and lower extremities (Rectus Femoris (RF)) to measure the muscle response of the subjects (Fig. 1b). SCM electrodes were placed mid-belly, CP electrodes centered along the longitudinal axis of the muscle and placed at the C5 level, and the UT electrodes were placed at the midpoint between C7 and the acromion. The ES electrode was placed mid-belly on the longitudinal axis of the muscle as the subject flexed forward at the pelvis. The RF electrodes were placed mid-belly as the subject extended their leg. A grounding electrode was centered over the right mastoidale. Signals from the muscle leads were passed to two battery-operated eight-channel FM transmitters (TeleMyo 2400T V2, Noraxon, Scottsdale, AZ) and recorded throughout each trial at 1500 Hz per channel. Within the EMG acquisition system, the signals from each of the sEMG electrodes were amplified (gain 1000) with a single-ended amplifier (impedance >10 M ohm) and filtered with a fourth-order Butterworth filter (10–500 Hz) (minimum 85 dB CMRR across entire frequency of 10–500 Hz; ADC resolution: 12-bit). The lower cutoff frequency of 10 Hz is intended to attenuate motion artifact. Each subject prior to sled testing performed maximum voluntary isometric contraction (MVIC) tests for attempted neck flexion, and neck, torso and leg extension for 10 s durations. For neck flexion and extension, the subjects were standing upright; however for torso and leg extension, the subjects were seated. EMG was recorded for all of the MVIC tests. Mean

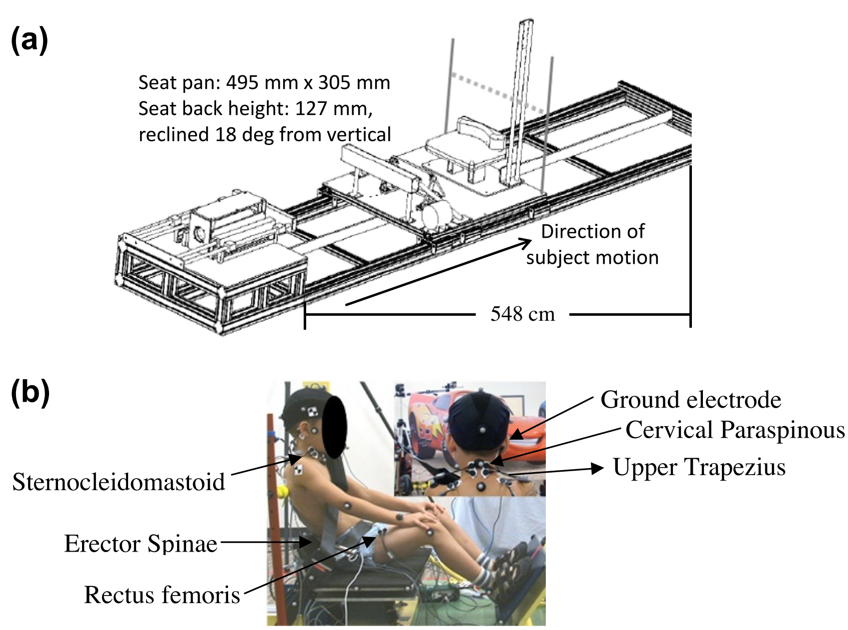

Fig. 1. (a) Schematic of low-speed acceleration sled and (b) surface EMG electrode locations on a child subject.