Clinical Biomechanics 30 (2015) 839–846

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Shoulder muscle forces during driving: Sudden steering can load the rotator cuff beyond its repair limit

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ARTICLE INFO

Article history:
Received 1 June 2014
Accepted 8 June 2015

Keywords:
Musculoskeletal biomechanics modelling
Shoulder functionality
Upper limb muscle forces
Driving
Steering
Daily activities
Supraspinatus
Surgical repair

ABSTRACT

Background: Driving is one of the most common everyday tasks and the rotator cuff muscles are the primary shoulder stabilisers. Muscle forces during driving are not currently known, yet knowledge of these would influence important clinical advice such as return to activities after surgery. The aim of this study is to quantify shoulder and rotator cuff muscle forces during driving in different postures.

Methods: A musculoskeletal modelling approach is taken, using a modified driving simulator in combination with an upper limb musculoskeletal model (UK National Shoulder Model). Motion data and external force vectors were model inputs and upper limb muscle and joint forces were the outputs.

Findings: Comparisons of the predicted glenohumeral joint forces were compared to *in vivo* literature values, with good agreement demonstrated (61 SD 8% body weight mean peak compared to 60 SD 1% body weight mean peak). High muscle activation was predicted in the rotator cuff muscles; particularly supraspinatus (mean 55% of the maximum and up to 164 SD 27 N). This level of loading is up to 72% of mean failure strength for supraspinatus repairs, and could therefore be dangerous for some cases. Statistically significant and large differences are shown to exist in the joint and muscle forces for different driving positions as well as steering with one or both hands (up to 46% body weight glenohumeral joint force).

Interpretation: These conclusions should be a key consideration in rehabilitating the shoulder after surgery, preventing specific upper limb injuries and predicting return to driving recommendations.

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1. Introduction

Driving is one of the most common everyday tasks. The function of the shoulder in driving is to provide actuation to steering and thus injuries to this structure can not only inhibit function, but these injuries might also be exacerbated by the steering function. The shoulder is a joint for which the active stabilisers (rotator cuff muscles) provide a greater proportion of restraint than the articulating surfaces or ligaments when compared to joints such as the hip or knee (Kedgley et al., 2008; Veeger and van der Helm, 2007; Yanagawa et al., 2008). Therefore, in order to understand the function of the shoulder, it is important to identify muscle activation levels.

Prior work using surface electromyography (EMG) has shown low correlation between the activity of the shoulder muscles and the movement of the steering wheel, and therefore, little is known about which muscles are active during driving (Solveig and Johnsson, 1975). Due to the fact that surface EMG is normally used for large superficial muscles (such as deltoid, trapezius, biceps and triceps), not all the muscles can be assessed simultaneously. According to the results of Solveig and Johnsson (1975), both the main flexors and extensors of the elbow are not the prime movers in turning the wheel. However, prior work has not allowed the quantification of the activation of deep muscles, such as the rotator cuff muscles, and the effect of driver position on this activation.

Therefore, the aim of this study was to quantify rotator cuff muscle forces during sudden steering in different postures. Due to ethical and practical limitations with needle EMG, a combined musculoskeletal modelling with kinematic and kinetic measurement approach is taken.

2. Materials and methods

2.1. Subjects

Eight healthy right-hand male subjects with no history of shoulder pathology participated in the study (age: 25 SD 4 years, height: 178 SD 10 cm, body mass: 71 SD 12 kg). Informed consent was obtained from each subject, and ethical approval was granted from Imperial College Research Ethics Committee (ICREC_12_1_15).

2.2. Apparatus

A driving simulator was designed and built with a user interface that instructs the subject to suddenly turn right or left in a random order;

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http://dx.doi.org/10.1016/j.clinbiomech.2015.06.004
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simulating an avoidance task. The simulator was set up to assess right upper limb function during turning to the left or right. The initial design of the simulator was conducted by Haynes (2005) to simulate driving a standard family vehicle. In this study, the simulator was modified to measure the external force. The task is completed when the wheel has been turned 65°. The forces at the hands are measured by a calibrated, strain-gauge-instrumented attachment on the driving rig (Fig. 1). Specifically, the system consists of four TML (FLA-5-23) strain gauges (Tokyo Sokki Kenkyujo Co. LTD, Tokyo) at each handle, using a full Wheatstone bridge configuration with a bending strain gauge arrangement. Torque resistance on the wheel is set at 4 Nm in order to simulate a standard driving torque (Li and Xian, 2013). Motion of the subject and simulator wheel is tracked using optical motion tracking (VICON Motion Tracking System, VICON, Oxford, UK) acquiring data at 100 Hz (Fig. 1). A micro analogue 2 (FE-366-TA) amplifier (Flyde Electronic Laboratories LTD, Preston) was used for the communication between the strange gauges and the VICON capture system. The output voltage was given in the VICON system synchronised with the motion tracking data. Four markers were placed on the handles, two on each handle (Fig. 1) to define the external force vector's direction for input into the model.

2.3. Protocol

Optical motion tracking markers were placed on the subject according to the landmarks recommended by the ISB (Wu et al., 2005) considering the upper limb as 5 segments: thorax, scapula, humerus, radius, and ulna. Specifically, the markers were placed on the radial styloid (most cauda-lateral point), ulna styloid (most cauda-lateral point), right and left acromioclavicular joint (most dorsal point), incisura

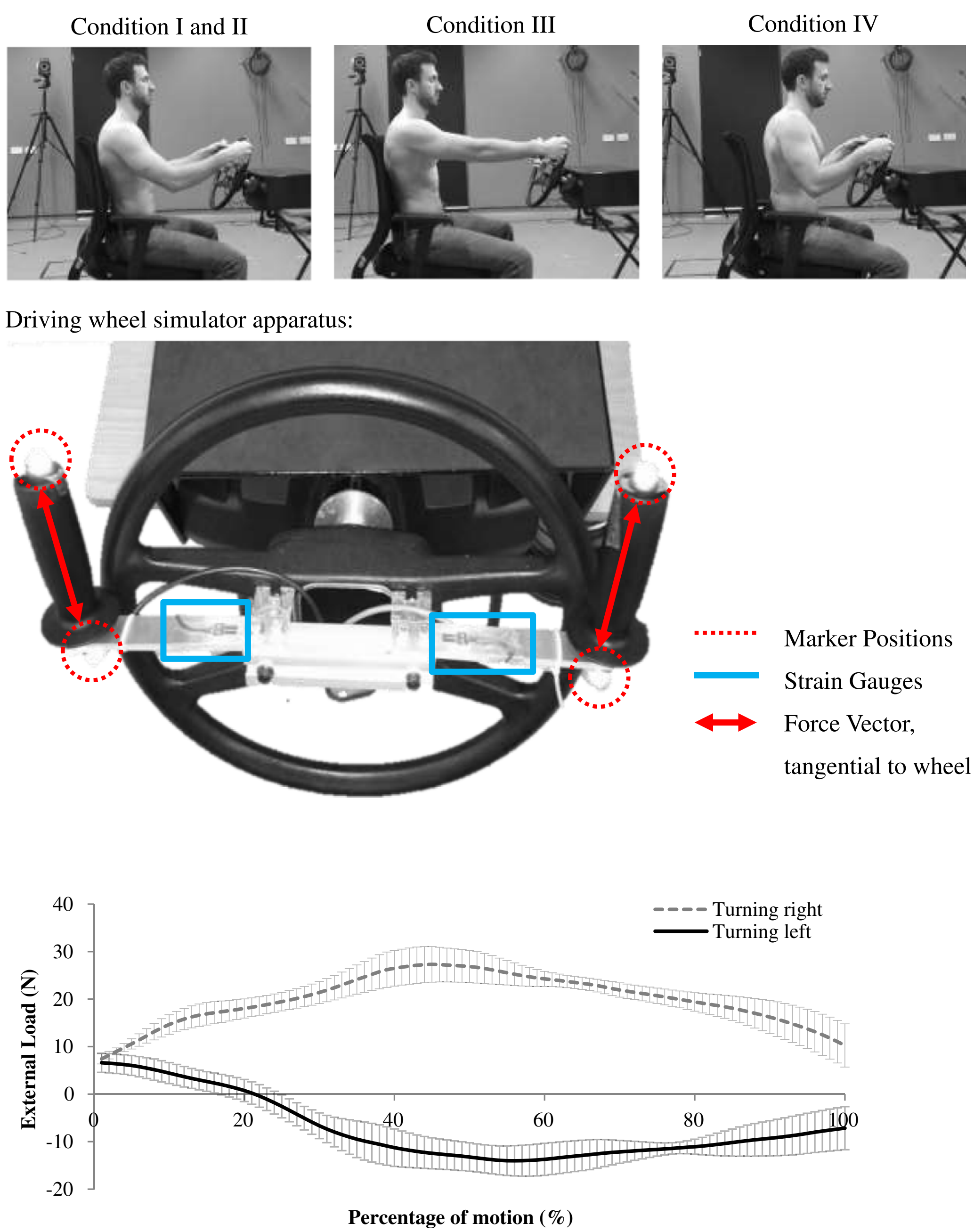

Fig. 1. (Top) Subject demonstrating three driving positions. (Middle) Modified driving wheel simulator showing marker positions with resultant force vectors and strain gauges. (Bottom) Mean external loading on the right hand and intersubject values of SD during steering right and left in a comfortable driving position (Condition I).

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