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Defining the upper extremity range of motion for safe automobile driving☆

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ABSTRACT

Background: There are no guidelines for return to driving following upper extremity injury. A greater comprehension of the role of the upper extremity in driving is required to assist clinicians in their fitness-to-drive assessments. This research aims to assist clinicians by analyzing the motion at the upper extremity in safe automobile driving.

Methods: Thirty-six participants were recruited to the Monash University Accident Research Centre's driving simulator. They were tested in a realistic driving simulation using highway scenarios and traffic hazards. An OptiTrack™ motion tracking system recorded participants' upper limb movements.

Findings: The following ranges of motion were recorded (left and right arm mean whole numbers): The shoulder flexed from 14 to 54°, abducted to 18°and adducted to 9°. Shoulder rotation ranged from 6° external to 32° internal rotation. Elbow flexion ranged from 35° to 72°. Pronation reached 77° and supination to 24°. Wrist flexion reached 34° and extension reached 23°. The wrist deviated to 17°radially and 38° ulnar. To avoid simulated hazards, the steering wheel revolved 57.2° (SD 19.2). The key movements in hazard avoidance are shoulder flexion, shoulder rotation, forearm rotation and wrist deviation.

Interpretation: Shoulder flexion, internal rotation and forearm rotation have been shown to be key upper extremity movements in safe driving. Clinicians can refer to the ranges of motion recorded in this investigation, or the driving task at hand in their fitness-to-drive assessments. The ability to revolve the steering wheel 100° exceeds the 95th percentile of the steering wheel revolution angle required to avoid simulated traffic hazards.

1. Introduction

Injury or surgery to the upper extremity is a common burden to the ageing and active Australian population (Australian Institute of Health and Welfare, n.d.-a; Australian Institute of Health and Welfare, n.d.-b; Australian Institute of Health and Welfare, n.d.-c). Following their initial post-operative consultation, orthopaedic surgeons are commonly asked when they believe their patients may begin driving (Nuñez and Giddins, 2004). The answer to this is unclear, as there are no commonly used guidelines or clinical tests for medical practitioners to assess driving fitness in temporary upper limb disabilities (Austroads, 2013; Chen et al., 2008; Cooper, 2007).

In the Australian state of Victoria, driving assessments focus on fitness to drive following permanent disabilities or chronic medical conditions (VicRoads, n.d.-a). Comprehensive driving assessments for these patients are reserved for occupational therapists (VicRoads, n.d.-b). These assessments are time consuming and not financially or geographically plausible for the plentiful Australians who have sustained injury, or surgery, to their upper extremity, which results in a transient period of disability (VicRoads, 2015).

Without a comprehensive understanding of driving fitness, patients may return to driving in an untimely fashion (Chen et al., 2008; Gholson et al., 2014; Musselwhite et al., 2016). This is concerning as patients may not be able to perform the driving tasks that are required to be considered safe on public roads. In addition, as insurance companies are reliant on medical assessments, and drivers must prove to law enforcement that they are not driving dangerously, patients are placed at risk financially, and legally (Gandhi et al., 2014; Nuñez and Giddins, 2004; Road Safety Act, 1986). On the other hand, recommending patients to not drive for longer than necessary can have an

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impact on their occupation and social lives (Chen et al., 2008).

The focus of the literature concerning driving after orthopaedic surgery is on the lower limb (DiSilvestro et al., 2016). These studies assess brake reaction time pre and post operatively and extrapolate a timeline for when patients should return to driving following orthopaedic interventions (MacDonald and Owen, 1988; Spalding et al., 1994).

The role of the upper limb is more complex. The literature focuses on the ability to drive in various forms of upper extremity immobilization. Immobilization studies have revealed the only casts that are definitively safe to drive in are short arm casts that preserve grip strength (Gregory et al., 2009; Mansour et al., 2015). Relatively strong and otherwise healthy patients may also drive in short arm casts that affect grip, but this has not been assessed in hazardous scenarios (Blair et al., 2002; Kalamaras et al., 2006; Stevenson et al., 2013). Stevenson's objective driving assessment used an occupational therapist derived scoring system and revealed driving in above elbow casts to be safe, provided that the only role of the arm is to steer, and grip strength is preserved (Stevenson et al., 2013). Slings immobilizing the dominant arm have been shown to have a detrimental effect on driving ability (Hasan et al., 2015).

Few studies have assessed when patients return to driving following shoulder surgery. The pattern in the literature is that more complex procedures resulted in patients waiting longer before returning to driving. Following sub-acromial decompression, patients waited 22.67 days, and 34.9 days if the operation included acromio-clavicular joint excision (McClelland et al., 2005). Following rotator cuff repair the median return to driving was 2 months (Gholson et al., 2014). Following shoulder arthroplasty, only 60–66% of patients returned to driving, and one patient listed driving as the most important activity he or she can no longer do (Lawrence et al., 2012). These timelines highlight the need for a functional and relatively strong and painless shoulder for safe driving.

To assist clinicians in reliably assessing their patient's capacity to drive, research should look to advance the understanding of the upper extremities role in driving, to quantify what is safe on public roads, to prevent road accidents and provide peace of mind for doctors, patients and the public. This investigation intends to lead the way in the development of a return to driving guideline or clinical test. Its aim is to analyse the range of motion of able-bodied persons required to safely drive an automobile in a driving simulator.

2. Methods

2.1. Study design

This is a prospective biomechanical study assessing the role of the shoulder, elbow and wrist joints in safe automobile driving, specifically, the range of motion and reaction times. It was performed in the driving simulator laboratories at the Monash University Accident Research Centre (MUARC), Clayton, Australia. Ethics approval was obtained through the Monash University Human Resources and Ethics Committee.

2.2. Recruitment

The investigators recruited 36 participants for this study. As the research was deemed a pilot study, an a priori sample size calculation was not performed. An email advertisement was sent to Monash medical students along with staff currently working at MUARC.

2.3. Inclusion and exclusion criteria

Participants were required to possess a driver's license permitting independent automobile transport on Victorian roads. Participants could not have any non-correctable sensory, motor or cognitive impairment that would adversely affect the simulation.

Fig. 1. Study participant performing the formal driving simulation in an OptiTrack™ motion tracking system. The study participant is seen wearing OptiTrack™ motion trackers and seated in the MUARC portable driving simulator. OptiTrack™ cameras can be visualized at various vantage points.

2.4. Materials

2.4.1. Driving simulator

The MUARC portable driving simulator was used in our study. The simulator was originally purchased from Eca Faros™ (Lannion, France) and has appeared in validation studies comparing it's data to real life on-road data (Godley et al., 2002). The behaviour of drivers in a driving simulator has been shown to closely approximate real driver behaviours with respect to lane position, speed, brake onset and risky driver behaviour (Devlin et al., 2012; Mullen et al., 2011).

As seen in Fig. 1, the simulator is a small cab in automatic transmission composing of authentic vehicle parts including a steering wheel, an adjustable chair, a gearbox, pedals and a seat belt. The visual images of the simulator were presented on 5 flat screen monitors providing a horizontal field of view of approximately 150°. The steering wheel provided realistic torque feedback. There was audio feedback of engine noise, and indicator signals through front and back speakers. The open roof assisted in optimizing vantage points for the motion tracking cameras. The driver seat was kept reclined at 20°. Participants could move the seat backwards or forwards to their preferred position. A 60 km/h speed limit was enforced with frequent signage.

2.4.2. Motion analysis

OptiTrack™ Flex 13 cameras were paired with Motive software technology (NaturalPoint Inc. Corvallis, OR, USA). OptiTrack™ technology has been shown to provide clinically accurate and reliable results (Carse et al., 2013). Eight Flex 13 cameras were used (see Fig. 1). The frame rate was set at 120 Hz. Joint angles were recorded using rigid body analysis and inverse kinematics. Although the human body is not perfectly rigid, for the purpose of measuring joint angles, the human body can be considered as an articulate system composed of rigid bodies (Roux et al., 2002).

ISB Joint angles between the upper extremity segments were defined and calculated according to the International Society of Biomechanics (ISB) recommendations for the elbow, forearm and wrist, but not the shoulder joint (Wu et al., 2005). This is because the ISB supports defining shoulder movement as elevation and axial rotation, which is not clinically meaningful for the application of this study. The Euler angle sequence used for the shoulder was flexion/extension, abduction/adduction, internal/external rotation. The ISB rotation order