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The effects of valve-handwheel height and angle on neck, shoulder, and back muscle loading

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ABSTRACT

The objectives of this research were to: (1) investigate the effects of handwheel height and angle of a valve on the muscle loading of shoulder, neck, and back muscles; and (2) identify a handwheel height and angle that best distributes the load of torque exertions to different muscles. Fifteen healthy male participants were recruited for this study. The handwheel heights included knee, elbow, shoulder, and overhead levels. The handwheel angles included 0°, 45°, and 90°. At each height-angle combination, participants performed an isometric torque exertion on a handwheel. During each trial, the maximum electromyography (EMG) activities were measured from the right and left anterior deltoids, trapezii, latissimi dorsi, and erector spinae muscles. EMG data were normalized and reported as percentages of reference contractions (RC). A two factor split-plot analysis of variance (ANOVA) and Tukey multiple pairwise comparison tests were performed to determine the significant effects. Results show that a handwheel at overhead 45°, which allows the greatest torque production, is associated with a concentrated load on the right anterior deltoid (94.1 %RC). At elbow level, participants were exposed to low loads on the shoulder and neck muscles, but that was compensated with higher loads on the back muscles. Based on the EMG results, the best handwheel height and angle appeared to be at shoulder 0°. At this height and angle, seven of the eight muscles were working at or close to their lowest EMG activities, while also allowing the production of relatively large torques (65.2 Nm).

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1. Introduction

Handwheel actuators are commonly used in various industries to regulate the flow of materials within a valve system, such as steam, refrigerant, fly ash, and oil (Mead, 1986). Some of the industries that utilize handwheels include the power generation, water supply, petroleum refinement, and chemical and waste industries. Handwheels are also used in the railway industry to regulate the movement of rail cars. Although some valves are motor operated, most handwheel valves are manually operated by repetitively turning a handwheel (Wieszczyk et al., 2009).

Valve-operations have been described as the most physically demanding task by plant operators (Jackson et al., 1992). In many cases, the torque required to manually turn a handwheel far exceeds operators' strengths (Jackson et al., 1992; Schulze et al., 1997; Parks and Schulze, 1998; Wood et al., 1999/2000; Al-Qaisi et al., 2015). Parks and Schulze (1998) conducted data searches on injuries for five downstream facilities of the Phillips Petroleum Company for a 3 year period. Results showed that 57% of back injuries and 75% of head, neck, and face injuries were associated with valve operations. In addition to the high torque demands, another issue in the field is that there is no standardized height or angle for handwheels. Handwheels can be found at various heights and angles. They can range anywhere from floor level to overhead height.

Past research sought to determine an appropriate height and angle for a handwheel in terms of the torque production capabilities of valve-operators at different handwheel heights and angles (Schulze et al., 1997; Wood et al., 1999/2000; Hoff, 2000; Attwood et al., 2002; Wieszczyk et al., 2009; Al-Qaisi et al., 2015). These studies show that handwheels at overhead level at 45° or 90° orientation allow the highest torque production relative to other handwheel positions. In general, the lower the work demand is relative to the operator's physical capacity, the lower is the risk of fatigue or injury. Therefore, a benefit of such a handwheel position is that, at a fixed torque, operators would be working at lower percentages of their maximum physical capabilities. However, the drawback of this handwheel position is that it requires work at overhead levels, which poses greater risk of shoulder and neck pain (Grieve and Dickerson, 2008; Aghazadeh et al., 2011).

An additional factor that is critical in determining an appropriate handwheel height and angle is the muscle loading distribution during torque exertions on a handwheel at different heights and angles. Wieszczyk et al. (2008) is the only study in the literature to incorporate an electromyography (EMG) to determine the biomechanical loading on the human body during valve operations. They evaluated the effects of only the height of a handwheel on the EMG activities of eight muscles, including the left and right pectoralis major, latissimus dorsi, erector spinae, and deltoid muscles. Three handwheel heights were considered, including knee, chest, and overhead levels. At each height, participants performed maximum isometric torque exertions on a vertically-oriented handwheel with a diameter of 45 cm. During each torque exertion, the maximum torque produced and the maximum EMG activities were measured. EMG activities were normalized to maximum voluntary contractions (MVC) and reported as a percentage of their corresponding MVCs. Results showed that at overhead height the erector spinae was less active than the other muscles. However, at knee height, the erector spinae was the most active of all the muscles, which may be because knee height requires moderate to severe trunk flexion. The high muscle activity of the erector spinae supports Wieszczyk et al.'s (2009) recommendation that handwheel actuation at knee height can be of a greater risk of low back musculoskeletal disorder. At chest height, the %MVCs of the erector spinae and latissimus dorsi muscles were higher than the %MVCs at the other heights. However, the authors still concluded that handwheel valves should be placed near chest level because the arms and trunk are near neutral posture. From a general perspective, this conclusion may be correct, but it would still need to be validated with further EMG or biomechanical studies of valve-operations.

This research examined the effects of both factors, height and angle of a handwheel, on the EMG activities of various muscles. Four handwheel heights and three handwheel angles, as well as their interaction effect, were examined. The objectives were: (1) to investigate the effects of handwheel height and angle on the muscle loading of shoulder, neck, and back muscles; and (2) to identify a handwheel height and angle that best distributes the load of torque exertions to different muscles instead of loading certain muscles excessively.

2. Methods

2.1. Participants

Fifteen male healthy participants were recruited from the student population at a university. Prior to the data collection, the experimental procedures and the demands of the testing were explained to the participants and their signatures were obtained on informed consent forms approved by the university's institutional review board (IRB). The Physical Activity Readiness Questionnaire (PAR-Q, British Columbia Ministry of Health) was used to screen participants for cardiac and other health problems, such as dizziness, chest pain, or heart trouble (Hafen and Hoeger, 1994). Any participant who answered yes to any of the questions on the PAR-Q was excluded. The average age, height, and weight of the participants were 23.4 (3.1) years, 179.8 (5.1) cm and 81.1 (12.1) kg, respectively. The age range of the participants was between 18 and 30 years.

2.2. Equipment

A 37.4 cm diameter handwheel was used to simulate a handwheel-valve system. This diameter size falls within the range of diameters commonly found in the field (Parks and Schulze,