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Evaluation of three principles for forklift steering: Effects on physical workload

Carina Rislund [a], Hillevi Hemphälä [b,*], Gert-Åke Hansson [c], Istvan Balogh [c]

[a] Department of Product and Production Development, Division of Design & Human Factors, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
[b] Ergonomics and Aerosol Technology, Department of Design Sciences, Faculty of Engineering, Lund University, SE-221 00 Lund, Sweden
[c] Division of Occupational and Environmental Medicine, Lund University, SE-221 85 Lund, Sweden

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ABSTRACT

The aim of this study was to evaluate the consequences on the physical workload of new solutions in the forklift cab environment for the driver by quantifying the physical workload on the neck, shoulders, arms and wrists as an effect of steering systems. Twelve male subjects conducted identical test cycles with three types of steering: normal, tilted and miniature. The physical load on the drivers was evaluated using goniometry, inclinometry and electromyography. No major differences were detected when comparing the normal to the tilted steering wheel. The miniature steering wheel showed, in comparison to the normal steering wheel, lower velocity for the right and left wrists, lower elevation and lower velocity for the left upper arm, a reduction in load on the right trapezius muscle, respectively, and most noticeably a 6-fold increase in the "static" load and a 10-fold decrease in the time for rest/recovery for the left wrist extensor muscles. The tilted steering wheel did not have any significant effect on the workload. However, the effects of the miniature steering wheel indicate an increased risk for over exertion resulting in disorders of the wrist and forearm for the left side.

Relevance to industry: When introducing new techniques or changes in technical systems, it is essential to evaluate the effects on the human workload with objective measurements.

1. Introduction

Work-related musculoskeletal disorders are the dominating factor behind reported long-term sick leave (more than 90 days) in Sweden (AFA, 2009). Disorders of the neck, shoulder, arm and lower back are more common among male workers in the transportation and warehousing industry compared to the general workforce (Arbetsmiljöverket, 2009).

Forklift drivers are exposed to a combination of factors known to contribute to work-related disorders such as static or sustained work and vibrations (ICOH, 1996). The proportion of male forklift operators who reported work-related disorders involving the neck and shoulder region during the last 12 months was greater than the average for male workers in general (Fransson, 2008).

Statistics show that 69% of all Swedish male forklift operators report repetitive work at least half the time during a normal work day, and 57% report that they experience demanding repetitive work on a daily basis (Fransson, 2008; Arbetsmiljöverket, 2003). Hence, there is a need to develop forklift systems that can reduce the physical workload.

Forklifts are frequently used for loading, unloading and carrying heavy loads in various industrial activities. Heavy lift trucks are used in the steel industry, in paper mills, in ports and for log handling. Forklifts are used by approximately 150 000 workers in Sweden and they are one of the most frequently used pieces of technical equipment (Sundström, 2010). Forklifts are used in situations that place high demands on accessibility and flexibility for handling various types of loads by using levers, joysticks, knobs and steering wheels. Load instructions are delivered directly to the operator through computerized load handling systems. The work is often carried out under stress.

Technological changes such as the introduction of computers, electronic transmissions and improved hydraulics have resulted in changes for the forklift driver. Today, levers and joysticks are more compact, multifunctional and operate with only a fraction of the force needed previously when the technology relied on mechanical transmission. However, work-related disorders are still reported among forklift drivers, indicating a need for further improvements.

* Corresponding author. Tel.: +46 46 222 3936; fax: +46 46 222 4431.
E-mail address: hillevi.hemphala@design.lth.se (H. Hemphälä).

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Despite the technological developments, related research that explores and evaluates new solutions is scarce. Hellsten and Petzäll (1989) pointed out the need for better design of the driver area. Bark (1995) studied the work situation for forklift drivers in high-bay warehouse environments and this resulted in a concept for an ergonomically adapted reach truck. Similar technological changes and their consequences have been reported from other areas such as forestry machines (Attebrant et al., 1997) and earth moving machinery (Kuijt-Evers et al., 2003).

The gradual change from heavy manual lifting to the use of technically advanced equipment, such as forklifts has involved a change in exposure and new risk factors. The risk factors in working life of awkward postures, repetitiveness and recovery time are well documented (Malchaire et al., 2001; Bongers et al., 2006; Descatha et al., 2007; Andersen et al., 2007; Waters et al., 2005).

One specific risk factor for forklift operators is vibration. Whole body vibration and lower back problems have been reported (Miyashita et al., 1992; Hulshof et al., 2006), but also hand-arm vibration and the effect of hand position (Morioka and Griffin, 2009).

In a review, Waters et al. (2005) found that most studies have focused on the risk of injuries, and only a few on the risk of musculoskeletal disorders. They conclude that "lower back pain seemed to be the risk, but studies should address not only lower back pain but also neck pain. A full exposure assessment of physical and non-physical factors in these studies is needed."

Work tasks now often involve repetitive movements, with long periods of lever and/or steering operations. This means a relatively low but static load on the driver. A relation has been documented between the position and velocities of the arm and disorders in the neck and shoulder region due to neck/shoulder strain and demanding visual perception (Eklund et al., 1994; Wiholm et al., 2007; Helland et al., 2008; Choi et al., 2009). Awkward postures and static postures are affected by cab design, seat, time spent seated, and the task performed (Barriera Viruet et al., 2008). Important aspects of forklift driving are the steering wheel and the driving performance (Davis et al., 2008). In order to prevent disorders, improvement of the equipment has been shown to be more successful than a personal approach (Shinozaki et al., 2001). Such interventions have involved forklift seats (Shinozaki et al., 2001) and arm rests (Attebrant et al., 1997). To succeed with redesign and interventions, Babapour et al. (2012) highlight the importance of product evaluations with user involvement. They conclude that companies and product developers would benefit greatly from conducting usability and ergonomics evaluations (i.e. theoretical expert analyses and evaluations with real users).

The aim of the study was to evaluate the effects on physical workload of a new steering system with a tilted steering wheel as well as a miniature steering wheel in relation to a traditional steering wheel by using objective and quantitative methods to measure the physical workload.

2. Subjects and methods

2.1. Experimental design

A laboratory study was carried out in which professional forklift truck drivers, with at least one year of experience, performed a standardized drive cycle designed to resemble realistic use situations. Three different steering systems were compared: a traditional steering wheel in normal position (normal), a traditional steering wheel in tilted position (tilted), and an armrest mounted miniature steering wheel (mini).

Twelve male subjects, all right handed, participated in the evaluation. The mean age was 47 years (range 37–62), mean height was 181 cm (range 172–198) and mean weight was 93 kg (range 57–126).

The drive cycle was derived from analyses of recorded driver behavior in order to define representative handling operations. The drive cycle was accommodated to focus on steering and circumstances at the test site; hence, lift operations were kept to a minimum.

The subjects each performed a driving activity using the three different steering systems in a balanced permutated order to avoid systematic errors due to order. With their left hand they controlled the steering and with their right hand they controlled the forks up and down, using electrical levers. The activity was to drive a lift truck in a pre-defined manner (drive cycle) during a 40 min session for each type of steering system, each cycle lasting approximately 4 min (see Appendix for drive cycle instructions). Cycle times were measured using a stopwatch when the forklift passed a specific start/finish line.

2.1.1. Drive cycle configuration

The tests were carried out on a paved rectangular asphalt surface, 50 m × 20 m. A plastic cone was used to mark the center (C). Six weights from 4 to 12 tons (normally used for tests) were placed at four positions A, B, D and E (see Fig. 1). A forklift truck with a lifting capacity of 12 tons was used for the tests.

The drive cycle was derived from recorded driver behavior in three different work environments that had been analyzed to define representative handling operations and their duration. Subjects were given 30 min before they started the test to get acquainted with the drive cycle, the forklift and the different steering systems. They were instructed to explore and practice the drive cycle and the equipment during this preparation time.

Subjects were instructed to perform a standardized drive cycle designed to resemble realistic driving conditions containing frequent turns and moves, both forward and reverse. Lift operations were kept to a minimum to allow maximum driving time. Through the combination of wide forks (0.35 m width at the tips) and wide fork pockets (0.40 m) on the weights, the task of lifting called for high precision and concentration.

During the 40-min sessions, one for each type of steering, the forklift drives repeated the pre-defined drive cycle. After 40 min, the subjects were instructed to complete the last cycle, stop for 5 min and then start anew with the next steering system.

2.1.2. Steering system

Three different steering systems were compared in this study:

2.1.2.1. Traditional steering wheel (normal). The first steering system consisted of a traditional steering wheel in normal position. The steering wheel contained a steering wheel assist knob with a diameter of 5.5 cm (see Fig. 2).

2.1.2.2. Traditional steering wheel, tilted to the left (tilted). The second steering system consisted of a traditional steering wheel

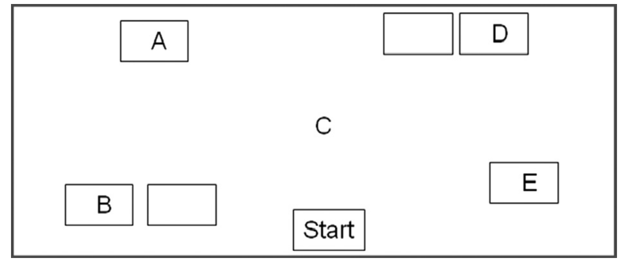

Fig. 1. Drive cycle configuration.