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Ergonomic evaluation of brake pedal and push handle locations on hospital beds

Jie Zhou [a, *], Neal Wiggermann [b]

[a] Department of Biological and Agricultural Engineering, University of California at Davis, Davis, CA 95616, USA
[b] Hill-Rom Services, Inc., 1069 State Route 46 E, Batesville, IN 47006, USA

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ABSTRACT

Transporting patients in hospital beds is a physically demanding activity performed by healthcare workers and bed design may moderate the risk of injury. Nine healthcare workers participated in a study to investigate how brake pedal location affected maximal voluntary exertion (MVE) force and the level of acceptable force for engagement. Preferred and acceptable push heights when maneuvering a bed were also evaluated. The method of limits was used to determine acceptable forces and push heights. Results demonstrated that pedal depth, clearance above, and clearance behind the pedal significantly affected MVE force and acceptable force. Preferred push height was approximately at elbow level and a single height would not accommodate the user population. These findings provide important considerations for hospital bed design. The method of limits was a valid and reliable approach for evaluating user acceptance of design inputs characterized by continuous variables and may be useful in other design evaluations.

1. Introduction

Musculoskeletal disorders (MSDs) continue to be one of the most serious health problems facing the working population, which not only cause personal suffering but also substantial economic burden (Lozano et al., 2013; Murray et al., 2013). Globally, MSDs account for 21.3% of the total years lived with disability (YLDs) and 6.7% of the total disability adjusted life years (DALYs) (March et al., 2014). In the United States, the total expense of MSDs in 2011 was found to be more than $800 billion including both direct (e.g. medical treatment) and indirect costs (e.g. loss of productivity) (Andersson 2015).

Healthcare workers (e.g. registered nurses, nurse aids) have long been among the most vulnerable occupations to MSDs (Bernal et al., 2015; Vieira et al., 2015). According to Bureau of Labor Statistics, in 2014, nursing assistants ranked second and registered nurses ranked sixth for occupations with the greatest number of MSDs in the United States (BLS, 2015). A recent literature review by Davis and Kotowski (2015) found that in the most recent year of work 55, 44, and 36 percent of nurses reported low back, shoulder, and lower extremity pain, respectively.

A substantial body of research has appropriately focused on manual patient handling as a risk factor for nursing injury (Jäger et al., 2013; Nelson et al., 2003; Wiggermann, 2015; Zhou et al., 2013), but relatively little attention has been paid to manual material handling despite being a common activity among healthcare workers (Poole-Wilson et al., 2015). Of particular concern is transporting a patient in a hospital bed for which high push forces (e.g., Wiggermann, 2017) and awkward postures (Kim et al., 2009) may impose an elevated risk of MSDs. The design of the hospital bed may affect the ease at which these transport tasks can be accomplished, but such designs have received little attention in the research.

The brake pedals on hospital beds often require substantial force to activate and awkward postures to reach because the pedal is usually recessed under the bed frame so as not to pose a trip hazard or interfere with the operation of other moving parts of the bed. Fig. 1a illustrates an example of a pedal recessed under a frame. Also the brake pedal can be positioned with comparatively large or limited clearance between the frame of the bed and the pedal (Fig. 1b and c, respectively). Only one study examined brake pedal location, investigating its effect on trunk posture, completion time, and self-reported task difficulty during brake engagement tasks

* Corresponding author. Department of Biological and Agricultural Engineering, University of California at Davis, One shields Avenue, Davis, CA 95616, USA.
E-mail addresses: jiezhou@ucdavis.edu (J. Zhou), neal.wiggermann@hill-rom.com (N. Wiggermann).

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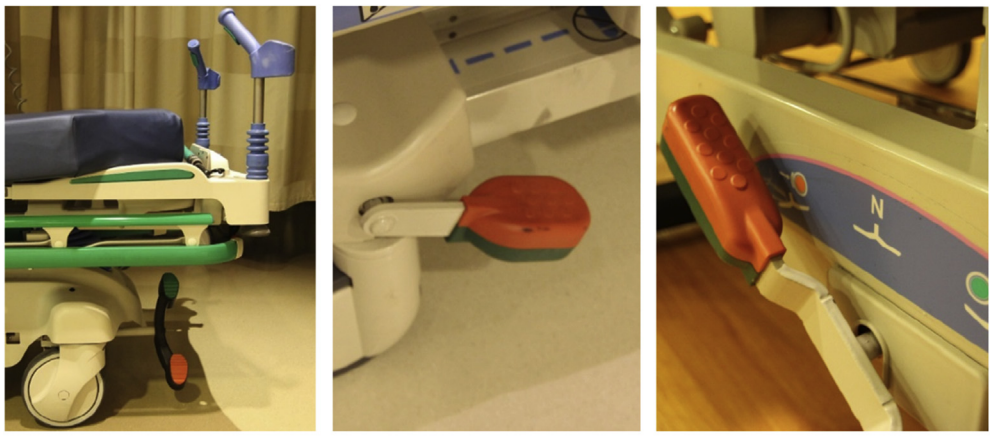

a b c

Fig. 1. a) Example of a brake pedal recessed under the deck of a stretcher, b) brake pedal design with clearance behind for the foot, and c) design with limited clearance for the foot.

(Kim et al., 2009). A brake pedal at the head-end of the bed was found to significantly increase trunk flexion angle and completion time, and thus was reported to be more difficult than a foot-end or side located brake pedal. However, Kim et al. (2009) tested only arbitrary pedal locations as they existed on two beds. The force applied to the pedal was not recorded and the pedal location was not systematically manipulated to understand the relationship between pedal location and force generation capability. This relationship is particularly important given that forceful exertions are one of the most important risk factors for MSDs (Keyserling, 2000). Finally, Kim et al. (2009) study included only young students who had no previous experience of brake engagement tasks so the results might not be generalizable to professional healthcare workers.

Like foot pedals, the position of push handles or grip points on a hospital bed has not been studied but is likely to affect the difficulty of transporting a patient. The height of pushing or pulling exertions has been shown to affect force generation capacity on fixed instrumented handles (e.g., Ayoub and McDaniel, 1974; Snook and Ciriello, 1991) or on carts (Al-Eisawi et al., 1999; Das et al., 2002; De Looze et al., 2000). However, hospital beds differ from carts in terms of size, weight, caster design, and visibility required by the user. Furthermore, most past studies of pushing tested only three discrete heights. There is no research that has studied subjectively determined preferred and acceptable pushing heights for users over a continuum of relatively small height intervals.

The method of limits has been successfully utilized in previous studies to detect various physiological thresholds (Gerr et al., 1990; Goldberg and Lindblom, 1979; Säterö et al., 2000), and it has been collectively suggested to be more reliable and easier to perform than other methods (e.g. forced choice method). Given that design requirements such as the force to actuate a foot pedal or the height of a push handle are continuous variables with a physiological threshold of "acceptability", the method of limits may also be useful in determining these thresholds. However, this validity has not been previously evaluated.

The primary objectives of the current study were to: 1) determine how the position of a hospital bed brake pedal affects the force that is acceptable for engagement and the maximum force that can be generated by healthcare workers, and 2) determine the preferred and acceptable pushing height for a healthcare worker moving a hospital bed. A secondary objective was to test whether the method of limits is valid for determining the acceptable brake pedal force and preferred handle heights.

2. Method

2.1. Participants

Nine professional healthcare workers (3 male and 6 female) employed in hospitals in Southeast Indiana and Southwest Ohio were recruited for this study. The healthcare workers included 3 registered nurses, 3 nurse aids, and 3 transporters (hospital workers specialized in transporting bed-bound patients between units). Their mean (standard deviation) height, weight and age were 173.5 cm (10.3 cm), 87.2 kg (16.9 kg) and 34.3 years (6.54 years). All participants were right footed and had at least 1 year of tenure in a position in which they regularly maneuver a hospital bed. Those who had an injury or condition in the trunk or lower extremity at the time of the experiment were excluded. All participants signed the informed consent documents and their anthropometric measurements (stature, acromion height, elbow height, trochanteric height and body weight) were recorded before the experiment. The total experimental time for each participant averaged 75 min, and the experimental protocol was approved Schulman IRB (Cincinnati, OH, USA).

2.2. Equipment and apparatus

For the foot pedal engagement task, a customized adjustable pedal comprised of a lever mechanism was built to simulate a range of pedal positions that are typical across several models of commercially available hospital beds. The pedal was located relative to the edge of the "bed" which was represented by a piece of steel angle with a 0.75-cm external radius that was suspended 37-cm off of the ground. This height is a typical location of the upper deck of a bed that partially restricts the user from reaching the recessed pedal. To determine the acceptability of the force required to actuate the pedal, counterweights of various magnitudes were attached at one end of the lever and the participant stepped on the opposite end of the lever to overcome the counterweights (Fig. 2). To measure the maximal force that could be generated by the healthcare workers, the lever was braced to prevent pedal movement and a three-dimensional force sensor (Model: MC3A-1K; AMTI; Watertown, MA, USA) was used to measure the force exerted on the pedal by the participant. A 3 cm $\times$ 8 cm injection molded plastic foot pedal from a hospital bed was attached to the surface of the load cell. During the maximal voluntary exertions, joint positions of the trunk, hip, knee and ankle were captured using a