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Hand forces exerted by long-term care staff when pushing wheelchairs on compliant and non-compliant flooring

Chantelle C. Lachance[a,b,c], Alexandra M.B. Korall[a,b,d], Colin M. Russell[a,b], Fabio Feldman[a,b,e], Stephen N. Robinovitch[a,b], Dawn C. Mackey[a,b,*]

[a] Department of Biomedical Physiology and Kinesiology, Faculty of Science, Simon Fraser University, 8888 University Drive, Burnaby, V5A 1S6, British Columbia, Canada
[b] Centre for Hip Health and Mobility, Faculty of Medicine, University of British Columbia, 2635 Laurel Street, Vancouver, V5Z 1M9, British Columbia, Canada
[c] Knowledge Translation Program, Li Ka Shing Institute, St. Michael's Hospital, 30 Bond Street, Toronto, M5B 1W8, Ontario, Canada
[d] George and Fay Yee Centre for Healthcare Innovation, Third Floor Chown Building, 753 McDermot Avenue, Winnipeg, R3E 0T6, Manitoba, Canada
[e] Patient Safety and Injury Prevention, Central City Tower, 400-13450 102nd Ave, Surrey, V3T 5X3, British Columbia, Canada

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ABSTRACT

Purpose-designed compliant flooring and carpeting have been promoted as a means for reducing fall-related injuries in high-risk environments, such as long-term care. However, it is not known whether these surfaces influence the forces that long-term care staff exert when pushing residents in wheelchairs. We studied 14 direct-care staff who pushed a loaded wheelchair instrumented with a triaxial load cell to test the effects on hand force of flooring overlay (vinyl versus carpet) and flooring subfloor (concrete versus compliant rubber [brand: SmartCells]). During straight-line pushing, carpet overlay increased initial and sustained hand forces compared to vinyl overlay by 22–49% over a concrete subfloor and by 8–20% over a compliant subfloor. Compliant subflooring increased initial and sustained hand forces compared to concrete subflooring by 18–31% when under a vinyl overlay. In contrast, compliant flooring caused no change in initial or sustained hand forces compared to concrete subflooring when under a carpet overlay.

1. Introduction

Falls among residents in long-term care (LTC) are a persistent problem, and the incidence of falls occur at a two to threefold higher rate compared to older adults residing in the community (Gillespie et al., 2012). In addition, LTC residents are more susceptible to injury in the event of a fall; while about 10–15% of falls among community-dwelling older adults result in a serious injury (Tinetti et al., 1995), approximately 30% of falls in LTC cause injury (O'Loughlin et al., 1993; Rubenstein et al., 1994; Stevens and Olson, 2000; Tinetti and Speechley, 1989; Tinetti et al., 1988). The high prevalence of falls and fall-related injuries in LTC may be because residents currently enter care homes with substantial frailty and are close to end-of-life (Kanwar et al., 2013). In the United States, the average length of stay for a resident in LTC before death is only 13–18 months (Kelly et al., 2010). This can be partially attributed to long waitlists for admission into LTC, as well as active decision-making among older adults to "age in place" and remain living in the community, with some level of independence, for as long as possible (Davey et al., 2004).

Given that residents of LTC are at a high risk for falls and injuries, compliant flooring is being explored as a potential mitigation strategy. Compliant flooring is a type of built-environment modification that can be installed in a care home as a flooring or subflooring system (Lachance et al., 2016a). Specific brands of compliant flooring can be installed with an overlay of hospital-grade vinyl overlay or carpet as a means to create settings that mimic the home and community life. Compliant flooring is designed to reduce the ground stiffness in the event of a fall and is a passive approach to prevention of fall-related injuries (Lachance et al., 2016a; Laing and Robinovitch, 2009; Laing et al., 2006). There has been a considerable amount of research conducted on compliant flooring over the past two decades (Lachance et al., 2017), and the current available evidence suggests that compliant flooring may be an effective and feasible approach for reducing the incidence and severity of fall-related injuries among LTC residents (Gustavsson et al., 2015; Lachance et al., 2017).

Other evidence, however, suggests that compliant flooring increases

Abbreviations: F_{init_dwn}, initial downward force; F_{init_fwd}, initial forward force; F_{init_res}, initial resultant force; F_{sust_dwn}, sustained downward force; F_{sust_fwd}, sustained forward force; F_{sust_res}, sustained resultant force; LTC, long-term care; MSI, musculoskeletal injury; N, Newtons; SD, standard deviation; SE, standard error; T_{init}, instant of peak forward force; T_{min}, instant of minimum forward force; $T_{sustained}$, the time interval beginning 1 s after T_{init} and ending 2 s before T_{min}

* Corresponding author. Department of Biomedical Physiology and Kinesiology, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia, V5A 1S6, Canada.
E-mail addresses: LachanceC@smh.ca (C.C. Lachance), dmackey@sfu.ca (D.C. Mackey).

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push forces generated by LTC staff when using rolling equipment, including floor-based lifts, hospital beds, and wheelchairs (Lachance et al., 2017). The number of studies examining the effects of compliant flooring on workplace safety is small, however, and only a few studies used healthcare workers as their participants (Lachance et al., 2017). No studies included in a recent scoping review examined the effects of purpose-designed compliant flooring while pushing wheelchairs (Lachance et al., 2017). This area warrants further investigation, as the use of mobility devices among residents, including use of wheelchairs, is substantial (Clarke et al., 2009). In a study examining the use of mobility devices among institutionalized older adults, more than 70% of respondents reported using some type of mobility device (Clarke et al., 2009). Notably, over half (54%) of respondents stated using a wheelchair to get around (Clarke et al., 2009), and wheelchair-dependent residents typically need assistance from care staff to mobilize throughout the care home (e.g., moving from the resident's room to a dining hall).

In the absence of widespread uptake of compliant flooring in LTC homes, healthcare staff in LTC are already at especially high risk of suffering work-related musculoskeletal injuries (MSIs) from patient handling tasks, which often involve components of pushing and pulling (Alamgir et al., 2007; Guo et al., 1995; Ngan et al., 2010) with rates of non-fatal occupational injury in the United States estimated at 7.1/100 full-time LTC staff per annum (US Bureau of Labor Statistics, 2014). In British Columbia, a province of 4.77 million residents, roughly 2600 LTC staff file compensation claims for overexertion injuries each year, accounting for nearly $17 million in direct claim costs, and more than 120,000 lost working days (WorkSafeBC, 2009).

Hand forces generated by pushing wheelchairs depend primarily on body weight of the individual sitting in the wheelchair, the rolling resistance between the wheels and the floor interface (e.g., wheel size, floor surface), task complexity (e.g., straight pushing, turning), experience, and on workplace geometry (e.g., the need to maneuver the wheelchair in confined spaces) (Boyer et al., 2013; Marras et al., 2009; Rice et al., 2009; Xu et al., 2013). Previous research indicates that external forces increase when wheelchairs are used over compliant flooring (vinyl overlay, 0.20 cm with Sorbothane underlay, 0.83 cm) and when moving heavier weights (i.e., to mimic heavy and/or bariatric individuals) (Minns and Tracey, 2011). Minns and Tracey (2011) noted that their investigation was preliminary, however, and did not specify whether their findings were derived from one or multiple participants or whether the participant(s) were familiar with pushing wheelchairs in a healthcare environment.

Accordingly, the primary aims of this study were to determine the effects of flooring overlay (carpet versus vinyl) and flooring subfloor (compliant rubber [brand: SmartCells] versus concrete), as well as resident weight (90th percentile versus average) on forces required for LTC direct care staff to push a manual wheelchair, and on their subjective ratings of pushing difficulty. We hypothesized that both hand forces and subjective ratings would be (a) higher on carpet overlay than vinyl overlay; (b) higher on compliant flooring underlay than standard concrete underlay; and (c) higher when pushing a wheelchair loaded with the 90th percentile than average resident weight.

2. Materials and methods

2.1. Participants

We recruited 14 frontline LTC staff from a 165-bed LTC site in British Columbia, Canada, including 11 health care aides and 3 licensed practical nurses, with an average 13.7 (SD = 9.0) years of work experience in a LTC setting. All participants were women and had mean (SD) height, weight, and age of 156.8 (5.4) cm, 71.4 kg (18.2) kg, and 41.7 (12.4) years, respectively. We studied women instead of men because the majority of LTC frontline staff are women, and they are at a higher risk for sustaining a MSI (Ngan et al., 2010). All participants had experience pushing wheelchairs to transport LTC residents, and they did not report any MSI to their employer within the last six months. All participants provided written informed consent, and the study was approved by the Research Ethics Boards of Fraser Health Authority and Simon Fraser University.

2.2. Apparatus

Participants pushed a manual tilting wheelchair that is commonly used in LTC (Orion 2, Future Mobility Healthcare Inc, Mississauga, Canada). The wheelchair net mass was 29.5 kg, had a load capacity of 158.8 kg, and was 129.5 cm in height and 69.0 cm deep. The front rubber wheels had diameter of 20.0 cm and width of 2.8 cm, and the back rubber wheels had diameter of 61.0 cm and width of 3.5 cm. The wheelchair handles were oriented at a 45° angle with respect to the ground and had fixed length of 114.0 cm. To ensure wheels were free of debris, the wheelchair was serviced prior to data collection.

We constructed an instrumented handlebar that was mounted to match the height and angle (45°) the original handles of the wheelchair. This handlebar contained four main components: a push bar for participants to push the wheelchair, a clamp to affix the instrumented handlebar to the wheelchair, an accelerometer, and a load cell.

We used a triaxial accelerometer (Opal, APDM, Portland, OR) to ensure precise orientation of the instrumented handlebar at the start of each trial to reduce measurement system interruption. Since the experiment was conducted in four different resident rooms (described below under experimental factors) and over multiple testing days in an active LTC site, the handlebar was taken off the wheelchair from time to time. Each time we clamped the instrumented handlebar (with load cell) to the wheelchair, we oriented it at an approximately 45° angle and then tightened the clamps. Tightening sometimes resulted in small angular shifts, so we used an accelerometer-assisted method (described below) to allow for precise measurement of the load cell orientation and resulting calculation of the desired load cell force components.

Using a piezoelectric, triaxial load cell (model 9074C, Kistler, Winterthur, Switzerland), USB-6218 BNC Data Acquisition Device (National Instruments, Austin, TX) we collected hand force data which was sampled at 1280 Hz, and custom MATLAB software routine. The load cell was custom mounted between existing wheelchair frames and a cylindrical handlebar (61.0 cm long, 3.2 cm in diameter; Fig. 1), to match the height and angle (45°) of the instrumented handlebar to that of the original handles of the wheelchair. To calculate load cell force components along a consistent set of forward/downward/left directions along horizontal/vertical/lateral push axes corresponding to the wheelchair orientation, the accelerometer was mounted with its axes aligned with the load cell axes. We calculated the relative orientation of the accelerometer, and the aligned load cell, based on the measured components of the accelerometer signal due to gravity while the system was at rest prior to the start of each trial. We then calculated the load cell force components in the directions of the push axes based on the relative orientation between the load cell axes and the push axes.

2.3. Experimental factors

We examined the effects of two independent variables on hand forces during pushing of the manual wheelchair: flooring system (4 levels: concrete + vinyl; compliant [SmartCells] + vinyl; concrete + carpet; compliant + carpet) and resident weight (2 levels: average LTC resident weight or 67 kg; 90th percentile resident weight or 90 kg). Participants completed all 8 combinations of conditions; the order in which they performed the conditions was block randomized at each factor level (flooring system then resident weight).

We conducted the experiment in four unoccupied resident bedrooms that were renovated for the study to each have one of the four flooring systems of interest (Table 1). The compliant flooring used for this study was 25.4 mm thick installed as a subfloor beneath vinyl or carpet