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Toilet Grab-Bar Preference and Center of Pressure Deviation During Toilet Transfers in Healthy Seniors, Seniors With Hip Replacements, and Seniors Having Suffered a Stroke

MATTHEW JOEL KENNEDY, MD, MSc1*, AMAYA ARCELUS, PhD2, PAULETTE GUITARD, PhD3, R. A. GOUBRAN, PhD, P.Eng.4, and HEIDI SVEISTRUP, PhD5

1Faculty of Medicine, University of Ottawa, Ottawa, Ontario, Canada
2CIHR-STIHR Health Care Technology and Place (HCTP), Intelligent Assistive Technology and Systems Lab (IATSL), University of Toronto, Toronto, Ontario, Canada
3Occupational Therapy School of Rehabilitation Sciences, University of Ottawa, Ottawa, Ontario, Canada
4Faculty of Engineering and Design, Carleton University, Ottawa, Ontario, Canada
5School of Rehabilitation Sciences, University of Ottawa, Ottawa, Canada

Multiple toilet grab-bar configurations are required by people with a diverse spectrum of disability. The study purpose was to determine toilet grab-bar preference of healthy seniors, seniors with a hip replacement, and seniors post-stroke, and to determine the effect of each configuration on centre of pressure (COP) displacement during toilet transfers. METHODS: 14 healthy seniors, 7 ambulatory seniors with a hip replacement, and 8 ambulatory seniors post-stroke participated in the study. Toilet transfers were performed with no bars (NB), commode (C), two vertical bars (2VB), one vertical bar (1VB), a horizontal bar (H), two swing-away bars (S) and a diagonal bar (D). COP was measured using pressure sensitive floor mats. Participants rated the safety, ease of use, helpfulness, comfort and preference for instalment. RESULTS: 2VB was most preferred and had the smallest COP deviation. Least preferred was H and NB. C caused largest COP displacement but had favourable ratings. DISCUSSION: The preference and safety of the 2VB should be considered in the design of accessible toilets and in accessibility construction guidelines. However these results need to be verified in non-ambulatory populations. C is frequently prescribed, but generates large COP deviation, suggesting it may present an increased risk of falls.

Keywords: assistive devices, workplace accommodations, high-risk fall patients, elder care, stroke

Introduction

Using the toilet is a common and essential activity of independent living that can become a difficult and even potentially dangerous task in some populations. Aging results in degeneration of vestibular, visual, and musculoskeletal and neuromuscular systems, as well as cognitive capacity. These natural consequences of aging can make the execution of activities of daily living more difficult and hazardous without adequate environmental modifications, in a progressive cycle termed “environmental press” by Lawton (1975). This degenerative process can be greatly accelerated and can result in greater deficits by traumatic events and illnesses. Osteoporosis and inactivity can predispose older adults to joint degeneration and bone fractures (Cummings et al., 1995) which accelerate physical functional loss, and often necessitate joint replacement surgeries. Hip replacement surgeries are increasingly common in Canada, and in 1998–1999, 335.3 hip replacements were performed for every 100,000 people aged 65 years or older—more than twice the rate in 1981–1982 (Millar, 2002). Hip replacement surgery often has a very good outcome on post-operative quality of life, and is considered a cost effective surgery (Norman-Taylor, Palmer, & Villar, 1996). However, of older adults who suffer from a hip fracture and undergo a subsequent hip replacement, only 43% return to pre-operative walking ability, and only 17% return to pre-operative ability to perform activities of daily living (van Balen et al., 2001). Dynamic balance is also reduced in individuals following hip replacement surgery (Nallegowda et al., 2003), and this, combined with reduced hip range of motion (Vogt, Brettmann, Pfeifer, & Banzer, 2003) and strength (Váz, Kramer, Rorabeck, & Bourne, 1993) makes activities such as toilet transfers more difficult. Another major cause of disability in older adults is cerebral vascular accidents, or strokes. Approximately 300,000 Canadians are currently living with the functional deficits of a stroke, which range from minor deficits to major disabilities which require long-term care. In fact, according to a report by the Public Health Agency of Canada (2009), 7.1% of Canadians aged 65 to 74 years old report living with a stroke, making it a very common cause.
of disability in older adults. Twelve to fourteen percent of strokes are pure motor strokes, but most strokes result in motor deficits ranging from decreased dexterity to quadriplegia, with the vast majority primarily affecting one side of the body (Arboix et al., 2001). Thus, most strokes result in difficulty performing normal motor tasks required for functional activities such as toilet transfers. In fact, in hospitalized stroke patients, 20% of the falls which they experienced occurred in the bathroom and during toileting, reinforcing the difficulty that toilet transfers can cause in stroke patients (Tutuarima, van der Meulen, de Haan, van Straten, & Limburg, 1997).

Sitting down and standing up from the toilet are potential causes of falls in the elderly and those with physical disabilities (Barbieri, 1983), and the installation of toilet grab bars have been suggested to help prevent falls in the elderly (Akyol, 2007). Furthermore, independence in toilet transfers is of major importance for maintaining autonomy. Bathroom aids such as toilet grab bars help to compensate for reduced physical capacity to allow for safer independent bathroom activities (Axtell & Yasuda, 1993), helping to prolong autonomy within the home.

Toilet grab bars are recognized as being essential for safe and successful toilet transfers in various populations, and thus there is legislation requiring their instalment in public washrooms and public housing (e.g., Canada Standard Association (2004, Ministry of Municipal Affairs and Housing (2006)). The utility of toilet grab bars is also well established in occupational therapy and rehabilitation disciplines, and these assistive devices are frequently recommended for or provided for residential use by people with temporary or permanent physical disabilities. In order for the appropriateness of toilet grab bar building code regulations and healthcare professional recommendations to be optimized, it is necessary to determine which grab bar configurations are best suited to special populations with a variety of physical impairments. It has been argued that current building code specifications concerning toilet grab bars are primarily based on the needs of young physically disabled people, rather than older adults with physical limitations (Czaja, 1984; Faletti, 1984), and that newer designs directed towards frail elderly would not meet current accessibility requirements (Hiatt, 1989). In fact, Sanford, Arch, and Megrew (1995) found that the toilet grab bar configuration preferred most by non-ambulatory older adults did not comply with either American or Canadian building code regulations. For this reason, it is essential that the toilet grab bar preferences of elderly participants both with and without physical disabilities, as well as the configurations which allow for the greatest transfer stability, be assessed so that these guidelines can be improved if necessary. Both Sanford et al. (1995), and Dekker, Buzink, Molienbroek, and de Bruin (2007) have analyzed a variety of toilet grab bar configurations for preference and perceived safety in older adults. However, neither group looked specifically at older adults who had undergone hip replacement surgeries or those who had suffered from a stroke. Furthermore, while the frequency of bar use (Sanford et al., 1995) and the location of hand placements on the bars during the toilet transfer (Dekker et al., 2007) were studied, the contribution of toilet grab bars on the control of center of pressure (COP) displacement on the floor during the sitting and standing procedures, an indication of postural steadiness (Prieto & Myklebust, 1993; Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996; Santos, Delisle, Lariviere, Plamondon, & Imbeau, 2008), has not been studied. Increased COP displacement during standing has been associated with increased risk of falling (Cheng et al., 1998), making it a good measure of postural steadiness in toilet transfers. This study is designed to assess the toilet transfer safety in ambulatory participants as opposed to those relying on wheelchairs. For the group being studied, COP displacement on the floor is an important measure of postural steadiness, whereas it may be less relevant in those transferring from a toilet to a wheelchair.

Thus, the purpose of this study was twofold. One purpose was to determine which toilet grab bar configurations are preferred by healthy older adults as well as older adults post-hip-surgery or post-stroke. The second purpose was to determine how these various toilet grab bar configurations contributed to the stabilization of the anterior–posterior displacement of the center of pressure (A/P COP) as participants sat down onto and stood up from a toilet as an indicator of transfer stability.

**Methods & Materials**

**Participants**

Twenty-nine people divided into three groups participated in this study. There were 14 healthy older adults who had no physical impairments, had no joint replacements, and could perform toilet transfers without difficulty (OLDER ADULT; 7 males) aged 64.0 ± standard deviation of 5.00 years old, 7 older adults having undergone at least one hip replacement (HIP; 2 males) aged 73.4 ± 8.34 years old, and 8 older adults having had at least one stroke (STROKE; 6 males) aged 65.9 ± 9.42 years old. All participants were ambulatory. None of the OLDER ADULT group used walking aids, three of the HIP group participants used a cane, and all STROKE participants used either a cane or four-leg walker. All participants were recruited from Ottawa community centers, social programs, or the University of Ottawa.

**Materials**

A bathroom prototype was designed for this study, consisting of two standard height 17 in. toilets (American Standard, Mississauga, ON, Canada). Placed directly in front of the toilets were two 25.4 cm x 101.6 cm pressure sensitive floor mats (Tactex Controls Inc. Victoria BC), one for each the right and left feet, which were positioned beside each other so that they extended lengthwise away from the front of the toilet. These pressure sensitive floor mats were connected to a computer via a USB cable, and data were collected at 30 Hz using digital data acquisition software. In addition to the floor mats, six toilet grab-bar configurations were built around the two toilets: a commode (C), two vertical toilet grab-bars (2VB)—one bolted to the floor, and one fixed to the wall—one vertical bar (1VB), a horizontal toilet grab-bar (H) fixed to the left side wall, two swing-away toilet grab-bars (S) fixed to the rear wall, and a diagonal toilet grab-bar (D) fixed to the right wall were used to aid in sitting down and standing up from the toilet (see Figure 1). The C, 2VB, 1VB, and H configurations were built around the first toilet, and the S and D toilet grab-bars were built around the second toilet. The 1VB, 2VB, D, and height of H configurations were positioned...
according the Ontario Building Code requirements, except that the H side bar did not extend far enough in front of the toilet (Ontario Building Code Compendium, 2006). The C and S configurations were positioned according to product specifications. The seat of the commode was raised to 20 in. high so that it just cleared the toilet seat, but all other configurations used the standard 17-in.-high toilet seat.

**Measures**

The raw data from the floor mats were processed using Matlab software (Mathworks, Natick, MA, USA). A/P COP data for the floor mats were calculated using a series of algorithms previously reported (Arcelus et al., 2009). A/P COP was only recorded when the average applied pressure on the floor mats produced a force over 25 N. COP displacement was calculated as the difference between the maximum and minimum COP values during the sit-and-stand cycles. In all participants, the minimum recorded COP value occurred at seat-contact or seat-off, and the maximum values occurred during the stance phases.

A Folstein Mini-Mental Exam (Folstein, Folstein, & McHugh, 1975) was used to ensure each participant had the cognitive capacity to understand and respond to the study questions.

Participant preference of each bar configuration was determined by rating the safety, ease of use, helpfulness, preference for installment, and comfort of the configuration using a five-point Likert scale (Sanford et al., 1995). Higher scores denoted favorable ratings. A composite rating score was then calculated by adding the five ratings together for a maximum positive rating of 25 and used as a measure of participant bar preference, as done previously by Sveistrup, Lockett, Edwards, and Aminzadeh (2006).

**Test Procedures**

Upon arrival at the laboratory, participants had the study explained to them in detail and were given a consent form to read and sign. All participants then completed a Folstein Mini-Mental Exam. All groups scored above 24/30 on the Folstein Mini-Mental Exam, indicating no mild cognitive impairment. Participants then entered the artificial bathroom and stood with one foot on each pressure mat directly in front of the toilet with their back facing the toilet. Following a verbal prompt, each participant performed five sitting and five standing trials on the toilet for each of the six toilet grab-bar configurations and an additional set of trials using no toilet grab-bars (NB). For each configuration with two bars, participants were asked to use both bars if they could, although some hemi-paretic stroke patients could only use one arm and thus one bar. Furthermore, due to hemiparesis, some STROKE participants could not complete some of the unilateral bar configurations (depending on which side the bar was installed and to what extent their arm was affected). This was determined by the participants either attempting and being unable to stand-up or sit-down after attempting the task or by stating they could not perform the task safely. Immediately after the sitting and standing trials were completed for each bar configuration, participants were asked to rate their bar preference based on the safety, ease of use, helpfulness, preference for installment, and comfort of the configuration. This study protocol was approved by the University of Ottawa’s Research Ethics Board.

**Data Reduction and Statistical Analyses**

All data were normally distributed and were statistically analyzed using parametric statistics. For participants in the HIP and STROKE groups, the floor mat pressure data were stratified by impaired and unimpaired limb. One HIP participant had bilateral hip replacements, and one STROKE participant had a bilateral stroke, so for these participants, the more recent hip replacement or the more severely affected hemi-paretic side was considered the impaired side. For both of these participants, the more recently involved limb was the more functionally impaired from the participant’s perspective.

To determine whether differences existed in sitting and standing variables between each toilet grab bar configuration within each group of participants (OLDER ADULT, HIP, and STROKE), within-group statistical analyses were completed. Between-group differences were not compared, since the goal of this article was to compare differences between the bar configurations and not between the groups.

The composite Likert bar rating score of each configuration was averaged for each group and then compared within each group using a within-group, repeated measures ANOVA for the stand-to-sit and the sit-to-stand conditions (α = 0.05). Post-hoc analyses were performed using a Bonferroni correction factor. The A/P COP floor mat pressure data for the seven toilet grab-bar configurations were averaged for each of the five sit-and-stand trials for each participant for each configuration and then compared across configurations within each group. Separate linear mixed-measures models were run using compound symmetry repeated covariance to determine differences for the stand-to-sit conditions and for the sit-to-stand conditions within each group. Estimated marginal means were then used to compare differences between configurations within each group. For the STROKE group, only two participants successfully completed the sit-to-stand and stand-to-sit maneuvers for the horizontal bar, so this...
configuration removed from the repeated measures analysis for COP displacement.

Results

Composite Ratings of Each Configuration

In the OLDER ADULTS, the D and 2VB configurations were the only bars rated significantly higher than 1VB and S conditions, whereas all configurations including NB were rated significantly higher than H. In the HIP group, all bar configurations were rated higher than the NB condition except for H and D configurations. For STROKE, all bar configurations were rated significantly higher than NB, and 2VB was the only configuration rated higher than H (see Figure 2).

Ability to Successfully Use Each Configuration

The OLDER ADULTS group successfully completed both maneuvers with all configurations. In the HIP group, 2 participants could not perform the sit-and-stand tasks with the NB configuration, and one participant could not perform the sit-and-stand for each of the 1V, H, and D configurations. In the STROKE group, no participants could both sit-and-stand with all configurations. For the C configuration, all participants could stand up, but 1 participant could not sit down. For each of the NB, 2V, SA, and D configurations 1 participant could not perform both maneuvers. Finally, 2 participants could not perform both maneuvers for the 1V configuration, and all but 3 participants could not sit down and stand up using the H configuration (refer to Table 1).

A/P COP Displacement in Floor Mat

Older adults. During the sitting task, the OLDER ADULT group had significantly smaller A/P COP displacement in the 2VB than the C and H configurations. The D configuration had significantly smaller A/P COP displacements than the NB, C and H conditions. Interestingly, these differences were only apparent when comparing the COP displacements of the right leg, and no significant differences were found in the left leg.

During standing, the OLDER ADULTS had significantly smaller A/P COP displacement in all configurations except for C when compared to H. In addition, both the 2VB and D configurations had significantly smaller A/P COP displacements compared to the NB, C, and S configurations. Finally, the 1VB configuration also had a smaller A/P COP displacement when compared to C. As with sitting, almost all significant findings only occurred in the right leg (see Figure 3).

HIP. In the sitting task, the HIP group demonstrated significantly larger A/P COP displacement in the C configuration than all configurations except for H and NB. 2VB also had a smaller A/P COP displacement than H and D, and 1VB also had a smaller A/P COP displacement than H. Most significant differences occurred in the unaffected limb, as this was likely the primary weight bearing limb, but the impaired leg also showed significant differences in the C and S configurations.

In the standing task, the HIP group demonstrated significantly lower A/P COP displacement in all configurations compared to the C configuration except for the NB configuration. The 2VB configuration also had smaller A/P COP displacement than the NB and 1VB configurations. As with standing, most significant differences occurred in the unaffected limb except for in the C configuration (see Figure 4).

STROKE. In the STROKE group for the sitting task, the NB configuration had significantly larger A/P COP displacement than all configurations except for C. All these differences were only found in the unaffected limb. No other significant differences were found.

In the standing task, the C configuration had significantly larger A/P COP displacement than 2VB, 1VB, and D configurations in the unaffected limb. 2VB also had smaller A/P COP displacements than 1VB and NB in the impaired limb (see Figure 5).

![Fig. 2. Composite rating scores of each toilet grab-bar configuration in older adults, those having undergone a hip-replacement and those who have suffered from a stroke. Each statistical comparison is between the bar ratings within the same group of participants; * = Significantly greater than Horizontal Bar Condition; † = Significantly greater than No Bar Condition; ♦ = Significantly lower than 2 Vertical Bar Condition; ‡ = Significantly lower than Diagonal Bar Condition.](image-url)
Table 1. The percentage of each group who could successfully sit down and stand up from the toilet using each of the various grab-bar configurations.

<table>
<thead>
<tr>
<th>Group (N)</th>
<th>No Bars</th>
<th>Commode</th>
<th>2Vertical</th>
<th>1Vertical</th>
<th>Horizontal</th>
<th>Swing Away</th>
<th>Diagonal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Older Adults (n = 14)</td>
<td>Sit</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Stand</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Hip Replacement (n = 7)</td>
<td>Sit</td>
<td>71.4</td>
<td>100</td>
<td>100</td>
<td>85.7</td>
<td>85.7</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Stand</td>
<td>71.4</td>
<td>100</td>
<td>100</td>
<td>85.7</td>
<td>85.7</td>
<td>100</td>
</tr>
<tr>
<td>Post-Stroke (n = 8)</td>
<td>Sit</td>
<td>87.5</td>
<td>87.5</td>
<td>87.5</td>
<td>75</td>
<td>37.5</td>
<td>87.5</td>
</tr>
<tr>
<td></td>
<td>Stand</td>
<td>87.5</td>
<td>100</td>
<td>87.5</td>
<td>75</td>
<td>37.5</td>
<td>87.5</td>
</tr>
</tbody>
</table>

Note: The percentages are bold font when not all participants from that group could sit or stand using the specified grab-bar configuration.

Fig. 3. The COP location and displacement in the A/P direction of both legs during sitting (A) and standing (B) in older adults. “L” indicates the left leg, and “R” indicates the right leg. The Y axis is the absolute distance in cm from the front of the toilet in the A/P direction, increasing as it moves in the anterior direction (away from the toilet). The solid black bar is the averaged COP displacement in the A/P direction, with the grey line indicating standard deviations; * = Indicates that the A/P COP displacement is larger than the corresponding leg A/P COP displacement with the two vertical bars condition; o = Indicates that the A/P COP displacement is larger than the corresponding leg A/P COP displacement with the diagonal bar condition; † = Indicates that the A/P COP displacement is smaller than the corresponding leg A/P COP displacement with the horizontal bar condition; ■ = Indicates that the A/P COP displacement is larger than the corresponding leg A/P COP displacement with the one vertical bar condition.

Fig. 4. The A/P COP location and displacement on the impaired (I) and unimpaired (U) side during sitting (A) and standing (B) in the HIP group. The Y axis is the absolute distance in cm from the front of the toilet in the A/P direction, increasing as it moves in the anterior direction (away from the toilet). The solid black bar is the averaged A/P COP movement, with the grey line indicating standard deviation; * = Indicates that the A/P COP displacement is larger than the corresponding leg A/P COP displacement with the two vertical bars condition; o = Indicates that the A/P COP displacement is larger than the corresponding leg A/P COP displacement with the diagonal bar condition; ◌ = Indicates that the A/P COP displacement is smaller than the corresponding leg A/P COP displacement with the commode condition; ■ = Indicates that the A/P COP displacement is larger than the corresponding leg A/P COP displacement with the one vertical bar condition.
Toilet Grab-Bar Preference and Center of Pressure Deviation During Toilet Transfers

Discussion

We recorded A/P COP data from three groups of older adults as they used seven different combinations of toilet grab bars as assistive devices during sitting onto and standing up from a toilet. In general, the groups preferred the configuration with two vertical bars (2VB), while the no bar (NB) and horizontal (H) configurations were identified as the least preferred. Although there were slight differences between groups, the two vertical bar (2VB) configuration resulted in consistently low amplitudes of A/P COP displacement for all groups and for both the sitting and standing task. In contrast, for all groups and both tasks, the commode (C) configuration was consistently identified with greater amplitudes of A/P COP displacement.

Limitations

Given the physical set up of the artificial bathroom, the H and D configurations were both wall mounted on a single wall, which posed a limitation for some participants in the STROKE and HIP groups, as the bar was located on their impaired side. However, this difficulty is often encountered in real-life situations, since most public bathrooms only offer grab-bars on one side. In a residential setting, an occupational therapy home assessment can help overcome this limitation by suggesting a more appropriate bar configuration for the specific bathroom design. It is also important to note that the position of the toilet grab-bars with each configuration also contributes to COP displacement and user ratings, and conclusions drawn about the orientation of the bar (horizontal, vertical, or diagonal) should also be interpreted in light of the bar’s position relative to the toilet.

The C was the only configuration with a raised toilet seat height, possibly making the transfer easier to perform by requiring reduced lower limb joint torques. This may in turn have biased the participant ratings in favor of C. However, this bias may be appropriate, given that it is an inherent feature of the device as it sits above the toilet. Toilet stalls with the other bar configurations can achieve this same feature by using toilets with raised seats. Interestingly, even with the elevated seat and reduced joint torques required to transfer, C still had the greatest displacement of the COP.

Finally, due to limitations in the setup of the toilet area, the H bar did not extend as far forward as recommended in the Ontario guidelines. In addition, only 2 participants from the STROKE group could successfully use this configuration because it was only available on their affected side, so it was removed from the A/P COP displacement analysis.

Bar Rating

Healthy older adults gave the 2VB and D bars the highest composite rating of safety, ease of use, helpfulness, preference for installment, and comfort of 21.75 (±2.47) and 21.96 (±3.97) out of a maximum of 25 (though not statistically significantly higher than all other configurations), and rated the H configuration the lowest with 14.05 (±5.14; see Figure 2). All configurations were rated significantly higher than the H configuration, with 1VB and S also being significantly lower than both 2VB and D configurations. Using a similar rating scale, Sanford et al. (1995) also found that the D configuration was rated highest in ambulatory older adults, with a short horizontal side bar having the worst rating. Because Sanford et al. did not test the 2VB configuration, the fact that they found the S configuration to be rated second highest was consistent with our results. Consistent with our 2VB results were the findings by Dekker et al., (2007) who reported that healthy older adults prefer vertical toilet grab bars for both sitting down and standing up from a toilet. The fact that the OLDER ADULTS rated the NB configuration the third highest may be accounted for by the stigma towards the use of physical aids in older adults (Aminzadeh & Edwards, 1998; Tinetti & Powell, 1993).

For the HIP group, the C, 2VB, 1VB, and S configurations were rated significantly higher than both H and NB
configurations. The C, 2VB, and 1VB configurations were not assessed by Sanford et al. (1995), but apart from these three configurations, the composite bar rating scores were similar between our independently ambulatory hip replacement participants and the non-ambulatory participants in the study by Sanford.

The STROKE group rated the 2VB, D, and C configurations highest and the NB and H configurations the lowest, however, the only statistically significant findings were that all bars were rated above the NB configuration, and 2VB was also rated above H. Interestingly, the STROKE group preferred the D configuration over the S configuration, whereas the non-ambulatory group in the study by Sanford (1995) rated the S configuration the highest. One possible explanation for this difference was that in the Sanford protocol, participants were required to navigate their ambulatory device over to the toilet in order to make the transfer, making a swing away bar very convenient for maximizing space, whereas in the present study, all participants began the sit-and-stand protocol once already positioned in front of the toilet. This is also an important consideration for the horizontal bar on the wall behind the toilet, which is only useful in either helping support the person while they stand facing the toilet to urinate, or in transferring onto the toilet from a wheelchair (Mace & Lasett, 1974). It is not typically used when standing in front of the toilet preparing for sit-and-stand transfers. However, the non-ambulatory participants in the study by Sanford also rated the horizontal bar configuration most poorly, and most questioned the utility of the back bar (Sanford et al., 1995).

**Ability to Successfully Use Each Configuration**

All participants from the OLDER ADULTS group could successfully sit and stand from all configurations. This was expected, given that these participants were healthy older adults, and none of them required assistive devices when toileting at home.

In the HIP group, 2 of 7 participants could not sit or stand with the NB configuration, and 1 of 7 participants could not sit or stand with the 1VB, H, and D configurations. All participants could successfully sit and stand with the C, 2VB, and S configurations. It was only 2 participants who could not use all of the configurations. Both participants were near the mean age of the group, one was male, the other female, and both only had one hip replacement. Both of these participants could not use the NB configuration. One could not use either the 1VB or the H, and the other could not use the D configuration. Interestingly, the one who could not use the D configuration was the only participant with a solitary right hip replacement, and the D bar was on the right side. While sitting or standing with the D configuration, the participant eccentrically or concentrically pulls themselves forward, and towards the side of the bar. Thus, when sitting or standing with a support bar which utilizes a pulling strategy, it is necessary to be able to generate the weight-bearing force with the ipsilateral leg. This may account for this participant being the only participant in the HIP group not able to sit or stand with the D configuration. The other participant had a left hip replacement and could not sit or stand with the either the left-sided H configuration or the 1VB configuration which was available on either the right or left side. In this situation, the side of the bar unlikely contributed to the inability to use it effectively. As mentioned, the 1VB was available on either side, thus the availability of the side of the bar did not contribute. As for the H configuration, it is used to push the participant eccentrically or concentrically up and away from the bar during sitting and standing respectively. Thus with bars which utilize a push strategy, it is necessary for the contralateral leg to be able to generate the weight-bearing force. In this participant, the side of the bar relative to the impaired leg does not explain the inability to use the bars effectively. In this case, it may have been due to general deconditioning of the unaffected leg, or other factors not measured in this study.

In the STROKE group, 1 of 8 participants could not sit or stand with the NB, 2VB, S, and D configurations. One could not sit down but could stand up with the C configuration. Two participants could not sit or stand with the 1VB configuration, and 5 of 8 participants could not sit or stand with the H configuration. Unlike in the HIP group, 6 of the 8 participants in the STROKE group could not use at least one of the configurations. Like the HIP group, the left side was most frequently the affected side, but unlike the HIP group, the affected side usually involved both the arm and the leg. As a result, the bar on the left side could often not be used irrespective of whether the weaker limb is on the ipsilateral or contralateral side. This may partially explain the reason for 5 of 8 participants not being able to sit or stand with the H configuration. Apart from this, there were no obvious trends explaining why specific participants could not successfully use each configuration.

**Anterior–Posterior COP Data**

When young healthy people rise from a seated position, they use a “momentum-transfer” strategy by using upper body momentum to transfer into vertical momentum, requiring lower joint torques and maximizing efficiency (Hughes, Weiner, Schenkman, Long, & Studenski, 1994; Riley, Schenkman, Mann, & Hodge, 1991; Schultz, Alexander, & Ashton-Miller, 1992). People change their standing strategy as they age, in ways to slow their ascent and increase stability by maximizing the time where their center of mass is over their base of support, but this occurs at the expense of efficiency—requiring higher joint torques (Lacour, Bernard-Demanze, & Dumitrescu, 2008; Mourey, Grishin, d’Athis, Pozzo, & Stapley, 2000). In order to achieve this, older people move their COP more anteriorly towards their base of support prior to seat-off to allow for decreased COM displacement during standing (Mourey et al., 2000). This adaptation occurs as a result of reduced balance and proprioception, in an effort to prevent falls. When this increase in required joint torques during standing is coupled with neuromuscular and musculoskeletal degeneration with aging, particularly after joint replacement or a stroke, appropriate assistive devices become necessary to sit and stand successfully. Given that the purpose of the altered standing strategy adopted by older adults is to maintain control over their center of mass over their base of support, which is closely reflected by the COP during the stance phase of slow controlled movements, it is important that the toilet grab-bars used to aid in toilet transfers help to minimize COP displacement. This is supported in a study by Cheng et al. (1998), who found that post-stroke fallers have increased A/P COP displacement during standing than post-stroke non-fallers. This is further suggested by Hewson, Singh, Snoussi, and Duchêne (2010), who found
that increased velocity of A/P COP (as occurs with momentum strategy) can predict elderly fallers compared with non-fallers when standing upright.

Specific sitting strategies are less well characterized between young and older participants. No information on changes in COP or COM characteristics during sitting as a function of age could be found. However, it was noted that older adults had decreased trunk angular velocity during sitting down, they took more time sitting down as compared to younger people, and they had decreased knee angular velocity during sitting down as compared to standing up (Mourey, Pozzo, Rouhier-Marcer, & Didier, 1998). However, it is uncertain how these differences would affect COP displacement during sitting.

For OLDER ADULTS, it was interesting to note that almost all significant differences in the A/P COP displacement were found in the right leg. This may be explained by the fact that 80% of the participants in the OLDER ADULT group were right side dominant and thus likely relied more heavily on this leg during the task. This is also suggested by the slightly more posterior location of the COP in the right leg across most configurations which would also suggest more of a reliance on this leg for force generation. In this group, the two toilet grab-bar configurations with the smallest A/P COP for both sitting and standing were 2VB and D, suggesting that they would be the best configurations for facilitating balance during the toilet transfer in older adults. The largest A/P COP displacement during both sitting and standing was observed with the H and C configurations, suggesting that these two configurations were the least helpful in limiting A/P COP displacement during toilet transfers in OLDER ADULTS.

For the HIP group, most significant differences were only found in the unimpaired leg. Like with the dominant leg in the OLDER ADULT group, this was likely because the unimpaired leg bore the majority of the participant’s weight. In the HIP group, the 2VB configuration had the smallest A/P COP displacement during both sitting and standing, suggesting that it is the best configuration for helping to maintain balance during toilet transfers. The 1VB and D configurations also had a relatively small COP displacement during sitting and standing, suggesting that vertical bars were best for the HIP group. The configuration with the largest A/P COP displacement during both sitting and standing was the C configuration, even more so than NB, suggesting that it is the worst configuration for facilitating balance during the toilet transfers. Thus, results seem to suggest that bars in front of the toilet are needed to facilitate pulling during the sit-to-stand motion and to allow hands to slide down bars for stabilization during the stand-to-sit motion. It is important to note that a unilateral pulling bar needs to be positioned on the side of the unaffected limb in participants with unilateral hip replacements. This may partially explain the benefit of the bilateral 2VB configuration over the other configurations.

Finally, in the STROKE group, significant differences in A/P COP displacement were found in both the impaired and unimpaired legs. However, the differences in COP displacement were most clinically relevant in the unimpaired limb, as it was primarily responsible for weight bearing. Consistent with this, the unimpaired limb was placed posterior to the impaired limb, which is consistent with reports from other studies (Roy et al., 2007) and is essential for generating the majority of force for sitting and standing tasks. In the STROKE group, the 2VB configuration had the smallest A/P COP displacement during both sitting and standing. The S, D, and 1VB configurations also had small A/P COP displacement during sitting, and 1VB and D also had relatively small A/P COP displacement during standing. The configuration with the largest COP displacement during sitting was the NB configuration, and the configuration with the largest COP displacement during standing was the C configuration. This suggests that these two configurations are the least helpful for maintaining balance during toilet transfers. This is of some concern, given that commodes are frequently prescribed for people with limited range of motion and strength. A possible modification which may increase the safety of C would be to lengthen the arms of the commode so they extend forward beyond the edge of the toilet, allowing the additional arm support to be over the base of support during the transfer. However, the effectiveness of this modification would need to be studied. As with the HIP group, it is important to recognize the importance of the side of unilateral grab-bars relative to the impaired side in hemiplegic strokes. However, it is a more complex relationship in STROKE participants as a result of the potential involvement of upper limbs in STROKE participants. This may also contribute to the added benefit of the 2VB configuration in toilet transfers in the STROKE group. The H configuration was not included in the COP analysis because only three participants could successfully use this bar because of it only being available on their hemiplegic side.

Conclusions

Overall, the least A/P COP displacement was consistently recorded by all groups when using the 2VB configuration followed by the D, 1VB, and S configurations in various orders. The greatest A/P COP displacement was observed with the C configuration followed by the NB and H configurations. The effect of the bar configurations on balance seem to be reflected by the user ratings, with the 2VB configuration having one of the highest ratings amongst groups and the H rated amongst the lowest by all groups. Interestingly, the C configuration had one of the highest ratings for both the HIP and STROKE groups but consistently one of the largest A/P COP displacements. The high rating may be a reflection of the lower effort required to stand due to the elevated seat. It is important to note that despite C being one of the most frequently prescribed toilet transfer assistive devices, it may be less safe than the other toilet grab-bar configurations. Toilet transfer fall risk in C versus other toilet grab-bar configurations should be further studied. Furthermore, given the convenience of portable commodes in rehabilitation, alternative designs such as one with support arms extending further forward should be considered and studied. Based on the results of this study, it seems that the 2VB is the most effective toilet grab-bar configuration, and it should be considered for inclusion in building code and accessibility guidelines. However, it should also be noted that this configuration requires two vertical bars fixed to the floor or walls, and this may interfere with navigation to and from the toilet in people who use wheelchairs and other mobility aids. Further research should assess the impact of the 2VB configuration on toilet stall and bathroom navigation in people with
mobility aids, and its feasibility for implementation into building guidelines. Another relevant observation was that there were differences between the OLDER ADULTS, HIP, and STROKE groups in toilet grab-bar preferences, and A/P COP displacement during toilet transfers. This information could be useful in designing accessible bathrooms or toilets for specific populations. It could also be useful when providing advice to individuals who are planning on installing bathroom grab-bars in their homes, based on their specific physical disabilities. The favorable ratings and reduced A/P COP displacement during toilet transfers with the 2VB configuration in all groups should be taken into account in the construction of accessible toilet stalls and bathrooms, and should be considered in accessibility construction guidelines. Moreover, these data highlight the need for multiple design options for addressing the wide spectrum of needs in individuals with disabilities and in healthy elderly people.

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References


